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TECHNICAL SUPPORT FOR

ROCKY MOUNTAIN ARSENAL

Rocky Mountain Arsenal  
Information Center  
Commerce City, Colorado

FINAL

REMEDIAL INVESTIGATION REPORT

VOLUME VI

SOUTHERN STUDY AREA

SECTIONS 1.0, 2.0, and 3.0 TEXT

VERSION 3.3

June 1989

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PREPARED FOR:

U.S. ARMY PROGRAM MANAGER'S OFFICE FOR  
ROCKY MOUNTAIN ARSENAL CONTAMINATION CLEANUP

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THE INFORMATION AND CONCLUSIONS PRESENTED IN THIS REPORT REPRESENT THE  
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SUBSEQUENT DOCUMENT. THIS REPORT CONSTITUTES THE RELEVANT PORTION OF THE  
ADMINISTRATIVE RECORD FOR THIS CERCLA OPERABLE UNIT.

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## STANDARD ABBREVIATIONS USED IN SOUTHERN STUDY AREA REPORT

### 1. Analyte Groups

VHO	Volatile halogenated organic compounds
VHC	Volatile hydrocarbon compounds
VAO	Volatile aromatic organic compounds
OSCM	Organosulfur compounds - mustard-agent related
OSCH	Organosulfur compounds - herbicide related
OPHGB	Organophosphorous compounds, GB-agent related
OPHP	Organophosphorous compounds, pesticide related
DBCP	Dibromochloropropane
ONC	Organonitrogen compounds
PAH	Polynuclear aromatic hydrocarbons
SHO	Semivolatile halogenated organic compounds
OCF	Organochlorine pesticides
ICP METALS	Metals analyzed for by inductively coupled argon plasma, includes cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn)
As	Arsenic
Hg	Mercury

### 2. National Acts & Organizations

AMCCOM	Armament, Munitions, and Chemical Command
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CWS	Chemical Warfare Service
DOJ	Department of Justice
DOD	Department of Defense
FDA	Food & Drug Administration
NCP	National Contingency Plan
NIOSH	National Institute of Occupational Health and Safety
SARA	Superfund Amendments and Reauthorization Act
USACOE	United States Army Corps of Engineers
USAEWS	United States Army Engineer Waterways Experiment Station
USATHAMA	United States Army Toxic and Hazardous Materials Agency
USDA-SCS	United States Department of Agriculture - Soil Conservation Service
USEPA	U.S. Environmental Protection Agency
USFWS	United States Fish and Wildlife Service

**STANDARD ABBREVIATIONS USED IN SOUTHERN STUDY AREA REPORT**  
(continued)

**3. Local Terminology**

BIM	Basic Information Maps
BCF	Bioconcentration Factors
BCRL	Below Certified Reporting Limit
CAR	Contamination Assessment Report
CDH	Colorado Department of Health
CDOW	Colorado Division of Wildlife
CRL	Certified Reporting Limits
EA	Endangerment Assessment
EC	Electrical Conductivity
ESA	Eastern Study Area
FS	Feasibility Study
PMCDIR	Program Manager for Chemical Demilitarization Installation Restoration
PMO or PMRMA	Program Managers Office for the RMA Contamination Cleanup
PWRS	Process Water Return System
RAA	Remedial Action Alternative
RI	Remedial Investigation
RIC	Resource Information Center
RMA	Rocky Mountain Arsenal
RMACCPMT	Rocky Mountain Arsenal Contamination Cleanup Program Managers Team
SAR	Study Area Report
SPF	Standard Project Flood
SPSA	South Plants Study Area
SSA	Southern Study Area
TPP	Technical Program Plan
TSP	Total Suspended Particulates
WSA	Western Study Area

**4. Companies**

EBASCO	Ebasco Services Incorporated
ESE	Hunter/Environmental Science & Engineering, Inc.
G&M	Geraghty & Miller, Inc.
MKE	Morrison-Knudsen Engineers, Inc.
WRS	Whitman, Requardt & Smith

**5. Unified Soil Classification System (USCS) Textural Key**

CL	inorganic clay, low plasticity
GC	clayey gravel
GP	poorly graded gravel
ML	inorganic silt, low plasticity
SC	clayey sand
SM	silty sand
SP	poorly graded sand
SW	well graded sand

STANDARD ABBREVIATIONS USED IN SOUTHERN STUDY AREA REPORT  
(continued)

6. Measurements

ac ft/mo	acre-foot per month
cm/yr	centimeters per year
f/cc	fibers per cubic centimeter
gpd/ft	gallons per day per foot
mg/kg	milligrams per kilogram, equivalent to parts per million
mg/l	milligrams per liter
msl	mean sea level
ppb	parts per billion
ppm	parts per million
ug/g	micrograms per gram, equivalent to parts per million
ug/l	micrograms per liter, nearly equivalent to parts per billion
umhos/cm	micromhos per centimeter

AA	Atomic Absorption
CVAA	Cold Vapor Atomic Absorption
Eh	Oxidation Potential
f <sub>oc</sub>	Soil-organic carbon content
GC/EC	Gas chromatography/Electron capture
GC/MS	Gas chromatography - mass spectrography
IL	Indicator Level
K <sub>d</sub>	soil-water partition coefficient
K <sub>h</sub>	Henry's Law Constant
K <sub>oc</sub>	organic carbon partition coefficient
K <sub>ow</sub>	octanol-water partition coefficient
NTU	Nephelometric Turbidity Units
TSP	Total Suspended Particulates



## TARGET LIST OF CHEMICAL ANALYTE GROUPS AND ANALYTES

### 1) Volatile Halogenated Organics (VHOs)

Methylene Chloride

Chloroform

Carbon Tetrachloride

1,1-Dichloroethane

1,2-Dichloroethane

1,1,1-Trichloroethane

1,1,2-Trichloroethane

1,1,2,2-Tetrachloroethane\*

1,1-Dichloroethylene

1,2-Dichloroethylene

Trichloroethylene

Tetrachloroethylene

Chlorobenzene

Trichloropropene\*

### 2) Volatile Hydrocarbons (VHCs)

Dicyclopentadiene

Bicycloheptadiene

1-Methyl-1,3-cyclopentadiene\*

Methylcyclohexane\*

Methylisobutyl Ketone

4-Hydroxy-4-methyl-2-pentanone\*

2-Pentanone\*

2-Butoxyethanol\*

2,2-Oxybisethanol\*

### 3) Volatile Aromatic Organic Compounds (VAOs)

Benzene

Toluene

m-Xylene

o- and p-Xylene

Ethylbenzene

### 4) Organosulfur Compounds, Mustard-Agent Related (OSCMs)

1,4-Oxathiane

Dithiane

Thiodiglycol

Chloroacetic Acid

\*Formerly a significant nontarget compound

TARGET LIST OF CHEMICAL ANALYTE GROUPS AND ANALYTES  
(continued)

- 5) Organosulfur Compounds, Herbicide Related (OSCHs)
- Chlorophenylmethyl sulfide  
Chlorophenylmethyl sulfone  
Chlorophenylmethyl sulfoxide  
Dimethyl disulfide  
Benzothiazole
- 6) Organophosphorous Compounds, GB-Agent Related (OPHGBs)
- Diisopropylmethyl phosphonate  
Dimethylmethyl phosphonate  
Phosphoric acid, tributyl ester\*  
Phosphoric acid, triphenyl ester\*  
Isopropylmethylphosphonic acid  
Methylphosphonic acid
- 7) Organophosphorous Compounds, Herbicide Related (OPHPs)
- Atrazine  
Malathion  
Parathion  
Supona  
Vapona
- 8) Dibromochloropropane (DBCP)
- 9) Organonitrogen Compounds (ONCs)
- Nitrosodimethylamine  
Nitrosodi-n-propylamine  
Hydrazine  
Methylhydrazine  
Unsymmetrical dimethylhydrazine  
Caprolactam\*
- 10) Fluoroacetic Acid
- 11) Polynuclear Aromatic Hydrocarbons (PAHs)
- Fluoranthene\*  
Methylnaphthalene\*  
Phenanthrene\*  
Pyrene\*

\* Formerly a significant nontarget compound

**TARGET LIST OF CHEMICAL ANALYTE GROUPS AND ANALYTES**  
(continued)

12) Semivolatile Halogenated Organic Compounds (SHOs)

Trichlorobenzene\*  
Hexachlorobenzene\*  
Hexachlorobutadiene\*  
Hexachlorocyclopentadiene  
Pentachlorobenzene\*  
Tetrachlorobenzene\*

13) Organochlorine Pesticides (OCPs)

Aldrin  
Dieldrin  
Endrin  
Isodrin  
Dichlorodiphenylethane  
Dichlorodiphenyltrichloroethane  
Chlordane

14) Arsenic

15) Mercury

16) ICP Metals (ICPs)

Cadmium  
Chromium  
Copper  
Lead  
Zinc

\*Formerly a significant nontarget compound

## EXECUTIVE SUMMARY

The Southern Study Area (SSA) Report defines the nature and extent of contamination in the southern portion of the Rocky Mountain Arsenal (RMA). This report integrates known historic information with the results of previous investigations and the Remedial Investigations (RI) of structures, soil, surface water, groundwater, biota, and air.

The SSA is characterized by a system of lakes, ponds, and ditches that were used to supply process cooling water to the South Plants industrial complex and by undeveloped land that borders on the Montbello residential and industrial area to the south of RMA. The main locations of activity that were of interest in the RI were Lakes Mary and Ladora, Lower, Upper, and Eastern Upper Derby Lakes, Rod and Gun Club Pond, Section 1 and 2 ditches, Section 3 overflow basin, Section 1 trash dump, Section 2 trench, Section 11 and 12 dredged lake sediment piles, various surface disturbances and sites of stressed vegetation, and undeveloped portions of Sections 1, 2, 7, 11, and 12.

Aerial photographs, operating records, facility drawings, and RMA personnel interviews were used to reconstruct the chemical history of the SSA. This history included the use of the ditches and lakes in the process water system and subsequent wildlife mortality related to this use; the dredging of sediments from the lakes and resultant disposal piles; and the use of other disposal areas in the SSA. This history indicated that the SSA was not used for the production of agents or pesticides, but that the SSA became the receptor of these contaminants from surface run-off and disposal practices in the SSA. The majority of the SSA served as a buffer zone around operations in central portions of the RMA.

The hydrogeologic environment, structures, air, and biota (wildlife and vegetation) of the SSA were studied during the RI to determine the presence of contaminant sources and to delineate the extent of contamination. The RI included a study of the SSA soils and a study of the geology of the surficial alluvium and the Denver Formation bedrock. The hydrology of these units and of the surface water in the SSA were also assessed. Structures and biota were inventoried, and climatic characteristics were defined.

Samples were collected during the RI to determine contaminant distribution and sources in the surface soils and vadose zone. This included the collection and analysis of 904 samples from 475 borings. Surface water samples were collected from all water bodies and ditches in and bordering on the SSA. Numerous wells were sampled to monitor groundwater in the water table and Denver Formation aquifers. Air and biota monitoring were conducted at RMA on a regional scale. These RI data and the results of previous studies were integrated to identify source areas and migration pathways, and to assess potential receptors of contaminants.

Organochlorine pesticides and mercury were the most commonly detected soil contaminants in the SSA. They were detected in the bottoms of the lakes, the Sand Creek Lateral, Sections 11 and 12 dredged sediment piles, and the Section 2 trash dump. Dibromochloropropane, arsenic, and some ICP metals were also identified in the bottoms of the lakes and in the Sand Creek Lateral. Semivolatile halogenated organic compounds and volatile halogenated organic compounds were found in a few scattered locations throughout the SSA; moreover, the semivolatile halogenated organic compounds were the only group found exclusively in soils and not in the other media (water, air and biota). The volume of potentially contaminated soil attributable to organic analytes was estimated at 940,000 cubic yards, of which 580,000 cubic yards were attributable to four organochlorine pesticides (aldrin, dieldrin, isodrin, and endrin). For inorganic analytes, the estimated volume of potentially contaminated soil above background levels totalled approximately 570,000 cubic yards.

The distribution pattern in soils of several volatile organic compounds, dibromochloropropane, SHOs, OCPs and mercury, are consistent with their expected behavior. The more volatile analytes (VHOs, VHCs, VAOs) were not detected in soils and appear to have either volatilized or infiltrated in vadose water to the water table. The semivolatile organic compounds (OCPs, SHOs, dibromochloropropane) were commonly found entrained on fine-textured sediments or on organic matter in ditches or more prevalently in the deepest portions of several lakes. The highest concentrations of several OCP analytes and mercury appeared at ditch discharge points to the lakes, where high energy delivery systems entered lower energy dispersal pathways.

Soil contaminants are actively migrating to other areas or media (i.e., ditches to lakes, upstream lakes to downstream lakes). However, analytes detected in the dredged lake sediments do not appear to be migrating to underlying groundwater or dispersing surface contaminants via eolian transport. This is probably due to the chemical behavior of the contaminants, media characteristics, and/or vegetative cover.

The principal migration pathway for organochlorine pesticides, dibromochloropropane, arsenic, mercury, and ICP metals is surface water. Volatile halogenated organics, volatile aromatic organics, and organochlorine pesticides were also detected in surface waters from ditches emanating from South Plants and from ditches coming onto RMA from the Montbello industrial and residential area to the south. Several drainage ditches from South Plants appear to be presently discharging sediment in run-off containing some of the analytes detected in the SSA which include volatile aromatic organics, SHOs, organochlorine pesticides, arsenic mercury, and ICP metals. This is evidenced by sediment dating procedures that indicate sediment is accumulating in the lakes at an approximate rate of 1.2 to 1.9 centimeters per year. Runoff is intermittent from the Section 1 and 2 ditches as well as those entering RMA from the south.

VHOs, VHCs, and the VAO benzene were the most commonly detected analytes in the groundwater of the SSA. Plumes of these contaminants were delineated emanating from the South Plants area. Contaminant mass flow rates were calculated for each of these contaminants and the results were: 160 grams/day for VHOs; 0.85 grams/day for VHCs; and 380 grams/day for benzene. OSCs, OPHs, and dibromochloropropane were only sporadically detected in groundwater throughout the SSA. The source of these contaminants appears to be South Plants, located north of the SSA, though OPHs and DBCP were also detected upgradient of these sites. DBCP is moving from the South Plants area to the east, south, and west into the SSA and eventually into the Eastern Study Area and Western Study Area. OCPs were also detected in groundwater north of the lakes area, possibly emanating from the South Plants area. The Section 2 ditches may also contribute OCPs to the groundwater in the SSA. VHOs detected in the same wells where OCPs were detected are apparently contributing to the

OCPs increased mobility. Arsenic, mercury, and ICP metals were found in groundwater throughout the SSA and do not appear to be linked to surface contamination sources. The presence and movement of all of the analytes detected in groundwater are consistent with their expected behavior.

Probable receptors of these analytes groups include downstream sediments, surface waters, downgradient groundwater, and deeper aquifers in the SSA. Some potential exists for uptake of organochlorine pesticides, mercury, and copper by terrestrial organisms, vegetation, and aquatic organisms. The potential uptake is most likely to occur in aquatic ecosystems, through direct contact or ingestion.

**FINAL  
REMEDIAL INVESTIGATION REPORT  
VOLUME VI  
SOUTHERN STUDY AREA**

**ERRATA SHEET**

Page xxiii, third paragraph, third sentence: Replace "This history indicated that the SSA was not used for the production of agents or pesticides..." with "This history indicated that the SSA was not used for the production or demilitarization of agents or the production of pesticides..."

Page 1-51: Delete the last sentence of the first paragraph.

Page 1-53: Delete the last sentence on the page.

Page 1-53, last paragraph, third sentence: Replace "This may be due to fractured portions of the Denver Formation claystone providing hydraulic connection between the aquifers, at least locally" with "this may be due to fractured portions of the Denver Formation claystone or the subcropping Zone A sandstone providing hydraulic connection between the aquifers, at least locally".

Page 3-79, first paragraph, second sentence: Replace "...plumes for two individual analytes..." with "...plumes for two analyte groups and one individual analyte..."

Figure SSA 3.4-21: Pattern designations are reversed in the legend. "Total area of potential contaminants in soils based on historical information and distribution mechanisms" should be represented by the dotted pattern while "Total area of detected contaminants in soils of all depths based on analytical result" should be represented by the dark shading.



## **1.0 STUDY AREA CHARACTERIZATION**

This section presents the physiographic characteristics of the SSA, discusses the scope of this report (including a summary of historic and ongoing investigations), and presents an historic summary of sites and nonsource areas within the study area. The geology, hydrology, and biota of the area are also discussed in detail sufficient to assess media contamination and initiate evaluation of Remedial Action Alternatives (RAAs).

### **1.1 PURPOSE AND SCOPE OF REPORT**

The purpose of the Southern Study Area (SSA) Report is to present the Army's Remedial Investigation (RI) results for the southern portion of Rocky Mountain Arsenal (RMA). This document is a formal RI product in accordance with the proposed Federal Facilities Agreement and Settlement Agreement (1988), the RMA Technical Program Plan (TPP) (PMO, 1988/RIC 88131R01), and the June 1985 U.S. Environmental Protection Agency (EPA) RI Guidance Document. The seven completed RI Study Area Reports (SARs), along with the RI media reports for air, biota, buildings, and water, fulfill the requirements of defining the nature and extent of contamination, and completing a comprehensive RI for the On-post Operable Unit of RMA as required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Superfund Amendments and Reauthorization Act (SARA), and the National Contingency Plan (NCP). The SSA Report integrates known historical information, the results of previous investigations, and the current RI programs for buildings, soil, surface water, groundwater, biota, and air to present an overall environmental contamination assessment of the study area as required under Contract Numbers DAAA15-88-D-0024. The SSA Report represents Volume VI of the overall RMA Remedial Investigation.

This RI report is presented in three sections. The characterization of the SSA is presented in Section 1.0. Contaminant distribution, based primarily on analytical results from the ongoing RI program, is presented in Section 2.0. Finally, Section 3.0 discusses the contamination assessment based on Section 2.0 data in conjunction with the physical features of the site discussed in Section 1.0 (e.g., geology, soils, hydrology, and biota).

This report summarizes a portion of the RI conducted at RMA by the U.S. Army Program Manager's Office for Rocky Mountain Arsenal Cleanup (PMO). The RI was performed over a large and diverse area, and included many tasks reported in separate Contamination Assessment Reports (CARs). Subsequently, the RI results from each task conducted in a specific geographic area were compiled and summarized in seven SARs. Additionally, four media reports were compiled to summarize RI results of water, buildings, air, and biota investigations at RMA. Brief descriptions of the results from these reports have been incorporated in this SAR. The RMA on-post RI consists of twelve volumes. Table SSA 1.1-1 lists the twelve volumes.

This report, Volume VI - Southern Study Area Report, integrates the site history, geology, and hydrology of the SSA with the chemical analytical results from soil, surface water, groundwater, air, and biota samples collected from the area. Collectively, these data have been evaluated to identify contaminant sources, distribution patterns, and migration pathways. The final section of this report summarizes contaminant distribution and migration assessments. The remainder of this section presents summaries of previous and ongoing investigations within the SSA.

#### 1.1.1 Summary of Previous Investigations

Several investigations have been conducted in the SSA since the mid-1950s and prior to the RI. All investigations and data that predate the RI are referenced as historical information for the purpose of this report. Early investigations were initiated as a response to wildlife mortality incidents in the lakes region (Sciple, 1952; Jensen, 1955; Finley, 1959). Later historical studies have included air and biota surveys as well as soils and hydrologic investigations. Since the focus of this report is on soils and hydrologic media, only historical reports pertaining to these resources will be referenced. Historical information on possible contamination of air, biota, and buildings can be found in Volumes III, IV, and V of this series. The results of previous investigations by Julius Hyman Company (1952), Shell Oil Company and its affiliate Shell Chemical Company (collectively referred to as Shell) (1957-1981), USATHAMA (1975), Geraghty and Miller (1982), the U.S. Army Engineering and Waterways Experiment Station (USAEWES, 1984/RIC 85133 R04),

U.S. Fish and Wildlife Service (1984), and Dames and Moore (1985) are included in this report and are used primarily as background information. All data presented within this report relate to historic records of the area's use as well as to soil, soil gas, surface water, and groundwater information collected in support of the current RI/FS program. Table SSA 1.1-2 presents previous investigations in the SSA.

#### 1.1.2 Summary of Remedial Investigations

As a result of the Cease and Desist Order issued in 1975 by the Colorado Department of Health (CDH), several source-specific and RMA-wide investigations have been conducted at RMA. Hydrologic, geologic, and contaminant studies were conducted from 1975 until 1984, when the RMA Decontamination Report (RMACCPMT, 1984a/RIC 84034R01) was developed by the Army for planning purposes. It identified and classified over 150 potential contamination sites and provided a preliminary assessment of the extent, probable use, boundaries, and possible contamination profile of these sites.

These sites were presented on an RMA-wide map that has become known as the "tricolor" map due to its use of three colors (pink, yellow, and blue) to graphically represent the likelihood of the site being an actual contamination source. These sites were delineated to concentrate the RI/FS on areas where contamination was most likely to be found. In addition, investigations were conducted in nonsource areas (i.e., those portions of RMA where there was no previous indication of potential contamination). Table SSA 1.1-3 lists the pertinent RI reports and investigations within the SSA. Figure SSA 1.1-1 is a map of the locations of the RMACCPMT designated sites in the SSA.

The results of investigations in the SSA were obtained primarily under RI Phase I Tasks 7 and 12 and Phase II Task 20, with additional information from RI Phase I and II Tasks 2, 4, 15, 22, 24, 44, and 48. Table SSA 1.1-4 summarizes these tasks and their specific work scope. Plate SSA 1.1-1 is a map indicating the location of all RI borings in the SSA.

## 1.2 LOCATION, PHYSIOGRAPHY, AND CLIMATE

The SSA is located in the south-central portion of RMA and consists of all of Sections 11 and 12 and parts of Sections 1, 2, 3, 6, and 7 (Figure SSA 1.2-1). The boundaries of the various study areas within RMA are generally based on contaminant-related activities as well as surface and groundwater characteristics. In general, SSA boundaries were established to include a system of lakes, ponds, and ditches that have been affected by sources of contamination in the South Plants Study Area. These features, as well as buried piles and trenches of dredged lake sludge and miscellaneous surface disturbances, are sites that have been detailed by previous contamination assessment reports.

The SSA is bordered by the Western Study Area (west), South Plants Study Area (north), Eastern Study Area (east), Stapleton International Airport (southwest), and the Montbello residential and industrial areas (south) (Figure SSA 1.2-1). The area southeast of Section 7 is mainly undeveloped land, including nonirrigated pasture. Directly south of Section 11 is a light industrial warehouse area.

The total area of the SSA is approximately 3.5 square miles; the topography is gently rolling and inclined toward the northwest, with elevations ranging from about 5,315 feet (ft) above mean sea level (msl) in the southeastern corner of Section 7 to 5,193 ft msl in the east-central portion of Section 3 (Figure SSA 1.2-2). Regionally, both surface and groundwater flow northwest, toward the South Platte River. Vegetation in the area varies, with weedy annual forbs, cheatgrass, mixed perennial grasses, shrubs, ornamental trees, and riparian habitat present.

Three relatively large man-made reservoirs (Lower and Upper Derby Lakes and Lake Ladora) occupy much of the SSA. Lake Ladora is in Section 2 and Lower and Upper Derby Lakes are in Section 1. These lakes have been used as part of a process water cooling system by the South Plants manufacturing complex (See Section 1.3).

Several smaller lakes and ponds also occur in the SSA (Lake Mary, Eastern Upper Derby Lake, Rod and Gun Club Pond, and the Havana Ponds). Lake Mary is a man-made pond, located west of Lake Ladora. It was created for recreational purposes and has been stocked with fish in the past. Eastern Upper Derby Lake is a small lake east of Upper Derby Lake that serves as an overflow catchment from Upper Derby via a metal culvert. The Upper Derby overflow channel on the northwestern side of Eastern Upper Derby directs excess water to the northeast toward First Creek. The Rod and Gun Club Pond, in the northern half of Section 12, receives overflow from Lower Derby Lake via a shallow ditch. The Havana Ponds are comprised of three natural depressions located in the southwestern quarter of Section 11. The ponds receive storm water run-off from two ditches, the Havana Street Interceptor and the Peoria Interceptor. The Havana Street Interceptor Basin, which is the northernmost pond in Section 11, was formed when an earthen dam was constructed in the 1970s. This dam was built as part of the drainage plan for the Stapleton International Airport runway expansion project. There is no information existing to suggest that this or other nearby ponds were used as disposal areas (CAPS, 1968; CAPS, 1975). The surface area of both the Rod and Gun Club Pond and the Havana Ponds increases substantially during periods of intense precipitation.

Eastern Upper Derby Lake and Upper Derby Lake are dry or marshy during most of the year except during unusually high rainfall events, such as occurred during the spring of 1988. Lower Derby Lake, Lake Ladora, and Lake Mary maintain near-constant water levels throughout the year. The levels of these lakes depends on flow regulation by RMA.

Five canals (Sand Creek Lateral, Uvalda Street Interceptor, Havana Street Interceptor, Highline Lateral, and Peoria Interceptor) deliver water onto RMA from the south. These ditches are dry most of the time except during intense storm events.

The lakes and ponds have been previously investigated as sites of potential contamination. In addition to these, several other sites have been identified and investigated within the SSA, namely: ditches, overflow basins, buried lake sediments, solid waste disposal sites, and other minor excavations and

surface disturbances. These sites and nonsource areas are discussed in detail in Section 1.3.

There are twenty-nine structures present in the SSA. Table SSA 1.2-1 lists each structure, the section in which the structure is located, its function, and the year it was built. Locations of the structures in the SSA are shown on Plate SSA 1.2-1. The Structures RI Report, Volume V of this series, contains detailed histories for each of the structures listed.

"C" Street forms the west boundary of the SSA and is paved. "E" Street, which forms a portion of the east boundary, is a gravel road. "D" Street, the major north-south route through the center of the SSA, is paved between Sections 1 and 2 but not between Sections 11 and 12. Fifth Avenue forms the south boundary of the SSA and is gravel. Numerous other unnamed gravel and paved roads provide access to the area. Other notable features are picnic areas in Sections 2, 11, and 12; earthen dams in Sections 1, 2, 3, 6, and 11; and a target range in the west-central portion of Section 12.

The climate of the RMA area has characteristic features of low relative humidity, abundant sunshine, relatively low rainfall, moderate to high wind movement, and a large daily range in temperature. The mean maximum temperatures range from 43°F in January to 88°F in July. The mean minimum temperatures are 16°F in January and 59°F in July. Annual maximum and minimum mean temperatures may vary by 28°F.

Occasionally, a meteorological phenomenon, known as the Chinook winds, descends along the eastern slope of the state from the west. These winds bring large and sudden temperature rises, as much as 25° to 35°F within a few hours. Chinook winds greatly moderate average winter temperatures in the RMA vicinity.

Precipitation in the RMA vicinity is approximately 15 inches per year. The evapotranspiration rate ranges from 24 to 30 inches per year (NOAA, 1957-1976). About half of the precipitation falls between April and July. Snow usually occurs from September to May with the heaviest snowfall in March

and possible accumulations as late as June. Thunderstorms occur frequently in the region, particularly during the spring and summer. They may be severe and are generally accompanied by heavy showers, severe gusty winds, and occasional hail.

Tornadoes develop during proper frontal action and convective instability commonly associated with intense thunderstorms in the RMA area. Several work trailers and buildings at RMA were damaged by tornadoes in the summer of 1986. Several small tornadoes touched down at RMA in June 1988.

The prevailing winds at RMA are from the south and south-southwest, paralleling the orientation of the foothills west of Denver. Wind speeds average about 9 mph annually (Figure SSA 1.2-3). Occasionally, winds are from virtually all directions, including the north-northwest, north, and east. The most windy months are March and April, with gusts as high as 65 mph. These months come immediately after the driest months of the year (November through February) and have the highest potential for dust storms.

### 1.3 HISTORY

For the purpose of this discussion, the history of the SSA is divided into two periods: prior to 1942 (before RMA was established) and after 1942. This report focuses mainly on the post-1942 time period; however, the pre-1942 period provides an historical, as well as chronological, context of how the area was developed, particularly with regard to land acquisition and man-made influences on drainage characteristics.

#### 1.3.1 Pre-RMA Use of the Study Area

Before RMA was acquired by the U.S. Army in 1942, primary land uses within the SSA were agricultural and rural residential. Of the four major water bodies present in the central and southern portions of the study area, only Lake Ladora and Lower Derby Lake existed prior to RMA's construction in 1942.

According to a permit claim filed with the State of Colorado, Office of the State Engineer, Lake Ladora was constructed at a cost of \$4,500 in the spring of 1919. The permit was filed by the Antero and Lost Park Reservoir Company

(Adams Co., Water District No. 2, Irrigation Division No. 1, May, 1919). The original specifications called for a 200 acre-foot impoundment that would flood 38 acres of lowlands. The permit claim indicated that the source of water for the Lake Ladora impoundment was "seepage and waste water. Sand seepage and waste being indirectly [distributed] to the South Platte River."

Although it is known that Lower Derby Lake existed prior to the purchase of lands for RMA use, no information was found relative to its actual date of construction. However, Lower Derby Lake is visible in a 1937 aerial photo. Also, in October 1942, the Army purchased the rights to 144 acres in Section 1 from the Reserve Mutual Water Supply Company (MKE, 1985). These 144 acres included the Derby Lake Reservoir and all standing structures and wells within the land parcel.

A review of records of the Colorado State Engineers Office in 1988 indicated that prior to the construction of Lake Ladora in 1919, a ditch named the Derby Seepage Ditch was constructed by the Antero and Lost Park Reservoir Company. This water channel was constructed in the spring of 1916 and was designed to carry up to 11.8 cubic feet per second. The drainage apparently traversed an area through the present Lake Ladora and exited from a point west of present day Lake Mary, into Section 3 to the west. Portions of this ditch are still visible; however, its use in carrying water appears negligible.

A historical review of literature documenting pre-RMA land uses in the SSA indicates that approximately 46 homesteads existed within the study area (Figure SSA 1.3-1) (MKE, 1985). Over three-fourths of the homesteads were within Sections 11 and 12. A review of property appraisal reports prepared by the U.S. Army during its purchase of RMA land indicates that a majority of the land in these two sections was devoted to grazing and irrigated farmland. Section 11 also contained numerous rural residential developments with names such as Desmond and Eire Gardens and the Scavo Subdivision. Section 12 consisted primarily of agricultural land with interspersed rural residential areas with names such as Avoca City, Ormond Gardens, Kincora Gardens, and Box Elder Farms (MKE, 1985).



Tracts in Sections 1 and 2, 3, 6, and 7 belonged to private individuals and two irrigation companies: the Antero and Lost Park Reservoir and Irrigation Company and the Reserve Mutual Water Supply Company. Many of the properties throughout the study area contained developed wells of varying construction and depths (MKE, 1985).

#### 1.3.2 RMA-Related Use of the Study Area

From the time RMA was established in 1942, various wastes may have been disposed and discharged into several portions of the SSA. These areas include six lakes and ponds in Sections 1, 2, 6, 11, and 12; an overflow basin in Section 3; two areas containing excavated buried lake sediments in Sections 11 and 12; ditch systems in Sections 1 and 2 that delivered process water to the lakes; a trash dump in Section 1 used for occasional disposal of steel and concrete debris; and a trench used for disposal of concrete debris and metal fragments possibly left from the testing of M-47 bombs (gasoline with napalm thickener). In addition, several small pits, trenches, storage sites, and numerous miscellaneous surface disturbances were investigated within the SSA during the RI.

Elsewhere within the SSA, the designated Nonsource Areas of Sections 1, 2, 6, 7, 11, and 12 have no recorded history of the use, storage, manufacture, or disposal of any chemicals or industrial wastes.

Each of the subareas defined in Section 1.2-3 is discussed below.

##### 1.3.2.1 Lakes and Ponds

The lakes and ponds in the SSA are: Lake Ladora, Lake Mary, Upper and Lower Derby Lakes, Eastern Upper Derby Lake, and the Rod and Gun Club Pond.

##### **Lake Ladora (Site 2-17)**

Lake Ladora is located in the southern half of Section 2 and occupies an area of 66 acres (Figure SSA 1.1-1) (Ebasco, 1987k/RIC 87216R07). Lake Ladora was man-made prior to RMA's construction. In 1942 the dam crest was raised 5 ft above the original elevation of 5,220 ft msl, enlarging the lake for use as a process cooling water reservoir. Until 1964, water from Lake Ladora was

pumped through the RMA process water cooling system, returned to Upper Derby Lake through a complex system of ditches, and allowed to flow by gravity to Lower Derby Lake. The water eventually flowed back to Lake Ladora and recirculated through the process water cooling system. Historically, water from Lake Ladora was used for irrigation, fire fighting, or in steam production. It is no longer used for crop irrigation, but it is used to water lawns. According to personal communication (1988) with Stearns-Roger, Inc., Lake Ladora is still available for fire fighting purposes (hydrants) but is seldom used in steam production because the water is quite hard.

#### **Lake Mary (Site 2-17)**

Lake Mary is located in the southern half of Section 2, immediately west of Lake Ladora (Figure SSA 1.1-1) (Ebasco, 1987k/RIC 87216R07). Lake Mary was created in a swampy area of seepage from Lake Ladora and occupies an area of 6.3 acres.

During the spring and summer of 1960, Rod and Gun Club personnel excavated the site and constructed a berm to create a small seven acre lake (Prentice, 1960; Donnelly, 1986). After construction and additional filling, the lake was stocked with fish. The earthen mounds observed in a 1963 aerial photograph partitioned the east half of Lake Mary into three areas that were used for rearing minnow-sized fish for release into the larger lakes (Mack, 1987).

Shallow sections of Lake Mary were dredged and tree stumps were removed during 1967 (Mack, 1967). During October 1974, Lake Mary was drained, enlarged slightly, and deepened to an average depth of 15 ft to enhance the quality of the water for fish (Mullan, 1975; Schmidt, 1975/RIC 84313R02). None of the reports reviewed during the literature search indicated that Lake Mary was included as an active component of the RMA process water system. The only apparent connection with that system was by subsurface seepage from Lake Ladora.

#### **Upper and Lower Derby Lake (Site 1-2)**

Lower Derby Lake is located in the southern half of Section 1, east of Lake Ladora, north of 6th Avenue, and west of "E" Street (Figure SSA 1.1-1) (Ebasco

1987h/RIC 87196R02). Upper and Lower Derby Lakes occupy a total area of 140 acres. Upper Derby Lake is a shallow marsh, with an elevation of 5,255 ft msl. The water level in Lower Derby is about 5,247 ft msl. The lakes occupy a natural depression with relief of about 15 ft. Lower Derby Lake was impounded sometime prior to 1937. In 1942, the Army expanded Lower Derby Lake by modifying the dam on the lake's west shore. Later that year, a 2,480 ft long dam was constructed on the lake's east shore, resulting in the formation of a second reservoir, Upper Derby Lake. Upper and Lower Derby Lakes were originally sealed with clay (Gatlin, 1960). Water from Upper and Lower Derby Lakes is used in the boiler plant, lawn sprinkler system, and fire hydrants.

Water for the lakes system (Ladora, Lower, and Upper Derby) is supplied from several sources: The Highline Canal via the Highline Lateral or Uvalda Street Interceptor; from three Section 4 wells; or from the potable water system in South Plants. The Uvalda Street Interceptor drains run-off from the Montbello residential development south of RMA to Lower Derby Lake. The ditch was constructed in the late 1960s.

#### **Eastern Upper Derby Lake (Site 6-2)**

Eastern Upper Derby Lake is located in the southwestern quarter of Section 6, east of "E" Street and north of 6th Avenue (Figure SSA 1.1-1) (Ebasco, 1987g/RIC 87196R03). Eastern Upper Derby Lake encompasses approximately 15 acres (RMACCPMT, 1984a/RIC 84034R01). The general elevation is 5,255 ft msl (Whitman, Requardt, & Smith, 1942), with a local relief of 3 ft. Eastern Upper Derby Lake was constructed in the early 1940s (Graef, 1943) to receive overflow through a corrugated metal pipe culvert from Upper Derby Lake (Trautmann, 1987). Although Upper and Lower Derby Lakes were originally sealed with clay to prevent seepage (Gatlin, 1960), there was no evidence that Eastern Upper Derby Lake was ever lined. Between 1963 and 1965, Eastern Upper Derby Lake was dry. During this time, Upper and Lower Derby Lakes were drained and excavated to remove contaminated sediment (Kenney, 1965). Since sediment analyses of Eastern Upper Derby Lake revealed negligible traces of contaminants, excavation and removal of soil in this lake was not recommended (Willis, 1964). By 1970 Eastern Upper Derby Lake held water again. After 1970 Eastern Upper Derby Lake was drained and allowed to revegetate. In 1973,

as a result of severe flooding on RMA, a 4 ft deep emergency spillway was constructed on one side of Eastern Upper Derby Lake along with an overflow channel connecting Eastern Upper Derby Lake with First Creek. Both units, the spillway and overflow channel, are presently used as emergency flood control drainage devices (Lutton, 1982).

#### **Rod and Gun Club Pond (Site 12-2)**

The Rod and Gun Club Pond is located south of Lower Derby Lake in the north-central part of Section 12 (Figure SSA 1.1-1) (Ebasco, 1987b/RIC 87127R04). The pond is connected to the lake by a shallow ditch that bisects the buried lake sediments in Section 12. The Rod and Gun Club Pond presently serves as an overflow basin for Lower Derby Lake. Currently, standing water occurs only in two 4 to 5 acre areas within the perimeter of the main pond. The pond encompasses an area of approximately 23 acres (Dames & Moore, 1985/RIC 85218R01). The Rod and Gun Club Pond and surrounding area were used for hunting water fowl and fishing from 1959 through 1979 (Thorne, 1982/RIC 83042R01).

#### **Contamination History of the Lakes Region**

A chronology of how the lakes were used in the manufacturing process and a review of contamination history in these areas is presented below.

The lakes in the SSA were used by RMA as part of the South Plants cooling water system. The process water system was a loop system composed of distribution and return water systems. It was designed and installed by the Army during the initial construction of RMA and was fully operational in late 1942. The original system serviced the South Plants manufacturing complex, which housed Army operations for the manufacture of military chemicals. The distribution system drew water from Lake Ladora and transported it through underground pipes to buildings where it was used for cooling purposes. The process water was returned to Upper Derby Lake by gravity flow through a network of open ditches and reinforced concrete, vitrified clay, and steel pipes comprising the process water return system. The water was recirculated through the lakes for storage and cooling and subsequently pumped back into the process water distribution system. One exception to the recirculation

system was the power plant spray pond (Building 326), which was designed to cool and independently recirculate the process water used in the condenser and turbine of the power plant (Building 325). Process water was used as makeup water for the spray pond recirculation system. Excess water could be removed either through a bypass connection between the spray pond return pipe and process water return system or through the spray pond overflow drain which discharged through a network of ditches and reinforced concrete pipe to the Sand Creek Lateral (COE, 1950b; CWS, 1945e; RMA, 1942; WRS, 1942; WRS, 1943).

Water was also occasionally added to the cooling water system from groundwater wells. In 1954, three alluvial groundwater supply wells and pump houses were constructed in the northwestern part of Section 4 to supply industrial makeup water to South Plants during dry periods when surface water was insufficient. A buried pipeline was built to carry the water from the wells to South Plants (AMSCOM, 1973/RIC 81339R20).

In the early 1950's, a study revealed that water from the phosphorus filling plants could be traced from specific buildings 522, 522A, 523, 523A, and 443 to an open drainage ditch that skirted the plants area. Seepage from the ditch was suspected to enter Ladora Lake via overflow during heavy rain storms (RLA006 1072).

In May 1951, there was an accidental discharge of caustic soda into the process water system at RMA, including Lake Ladora, which raised the pH level of the water to 10.5 and caused a massive fish kill (Armitage, 1951; Goodall, 1951). In addition, samples of surface water, surface foam, green algae, and sediment from Lake Ladora and Lake Mary revealed the presence of aldrin, dieldrin, gardona (a Shell insecticide), and bidrin (an organophosphate insecticide), and heavy metals (Julius Hyman & Company, 1952; Finley, 1959a; DOD, 1964; Kauffman, 1972/RIC 81295R07; Ferentchak, 1970; DOD, 1973). In the early 1950s, field and laboratory studies were conducted by the USFWS (Sciple, 1952) after observing a substantial number of waterfowl deaths and severe off-post crop damage. During their investigation, an oily scum was discovered on the South Lakes surface, but was not analyzed. At about this time, water studies from Lower Derby Lake were conducted by the Toxicology Branch of the

Army Chemical Center in Maryland. Samples, excluding the oily surface scums, were reported to contain no toxic compounds. In May 1952, Shell documented the first occurrences of pesticides in these lakes. Low concentrations of dieldrin (1 ppm) were detected in the lake surface water, and aldrin (68 ppm) was detected in the foam (Hyman, 1952b). Analysis of the scum from the lakes in 1953 revealed the presence of dieldrin and aldrin (Hyman, 1953). Concentration levels were not reported. However, lab analyses two years later did not detect any pesticides. In February 1964, foam and scum on the weeds in the process water return ditch were sampled and showed low levels of aldrin (3.5 ppm) and isodrin (0.2-0.3 ppm). There was no indication as to whether the insecticides had recently come from the plants area or had previously existed in the process water system and were recirculated (MKE, 1987).

There was no indication that waste was disposed directly into Lakes Ladora and Mary. The two lakes reportedly received contaminants indirectly through pipelines and ditches from the following sources: (1) recirculated process cooling water that may have become contaminated as a result of defective equipment (RMA, 1964; Lang, 1967; Adcock, 1978; Unauthored, 1952); (2) contaminants from the lime pits that migrated through Lower Derby Lake and through the inlet channel into Lake Ladora (PMCDIR, 1977/RIC 81266R68); and (3) aldrin and dieldrin from Shell operations such as cleaning contaminated material in the salvage yard (Lando, 1957).

Concerns were raised in the early 1950s that Upper and Lower Derby Lakes and Lake Ladora were contaminated with aldrin and dieldrin (and/or their intermediates) as a result of either accidental releases into the process water return lines and/or surface water run-off. In June 1952, the Army suspected dangerous water conditions and banned the use of Lower Derby Lake for recreational swimming (Smith, 1952). Throughout this period, excessive numbers of dead waterfowl were found in the vicinity of Upper and Lower Derby Lakes and Lake Ladora (Sciple, 1952/RIC 87296R01). As a result of these mortality incidents, additional field and lab studies conducted by the U.S. Fish and Wildlife Service (USFWS) estimated 1,200 ducks died near the three lakes within a three month period. In 1955, the USFWS summarized Sciples' 1952 study and supplemented it with additional epidemiological work (Jensen,

1955). Concentrations of dieldrin and related compounds were detected in concentrations as high as 261 parts per million (ppm) in the fat and liver of ducks found near the lakes. In April 1959, the Denver Wildlife Research Laboratory of the USFWS began a multi-year field and laboratory investigation of waterfowl mortality around the south lakes (Finley, 1959a). The study concluded that waterfowl losses totalled more than 2,000 birds annually. This study reported a significant correlation between duck mortality and the amount of exposed contaminated lakebed sediment. The investigation also reported that the chlorinated hydrocarbons present, notably aldrin, dieldrin, and their intermediates, had been identified as constituents in oily scum in lake waters and adversely impacted the environment to a significant degree (Finley, 1959b; USFWS, 1962/RIC 86041R02). In 1959, Finley reported that the lakes did not support fish, amphibians, or aquatic insects.

Shell and the Army initially sought to inhibit waterfowl mortality by keeping Upper Derby Lake either entirely full or totally dry (Gatlin, 1960). In late 1963, Shell and the Army agreed that the three lakes were contaminated with several organic compounds in concentrations of up to 2,400 ppm (Sheldon & Crabtree, 1965/RIC 87091R02). Measures were taken in the spring of 1963 to drain Upper Derby Lake and reroute the process water return canal to Lower Derby Lake. The USFWS recommended that the extent of lakebed contamination be fully characterized. In the fall of 1963, the Army decided to drain and sample Upper and Lower Derby Lakes. In early 1964, Shell again modified the process water return system by constructing a temporary diversion ditch to reroute process water directly to Ladora Lake. In late 1963 and early 1964, sediment sampling began in the lakes by the Corps of Engineers (COE, 1964).

Core sampling and analyses by the USFWS for aldrin and dieldrin indicated that contaminants were present in the sediment in both Upper and Lower Derby Lakes. Analytical results from 800 sediment samples collected from process water ditches and from the bottom of Upper Derby Lake indicated that these compounds were present in concentrations ranging from 5 to 20 ppm (Donnelly, 1964). Concurrent sampling by Shell Chemical Company detected concentrations of aldrin (up to 183 parts per million (ppm)), dieldrin (up to 12.7 ppm), isodrin (up to 8.3 ppm), and endrin (up to 10 ppm) in sediments from Upper and

Lower Derby Lakes. These compounds were not detected in sediments from either Lake Ladora or Lake Mary. Excavation and dredging of both lakes began in the summer of 1964. Four to six inches of the lake bottoms were initially dredged. Subsequent sediment studies located areas where pesticides were still heavily concentrated in the two Derby Lakes and Lake Ladora, prompting the removal of an additional 6 to 24 inches of sediment (Sheldon & Crabtree, 1965/RIC 87091R03). Contaminated soil (lake sludge) was deposited at the center of the northern edge of Section 12 and in Section 11. On June 17, 1965, the process water return flow was diverted back to Lower Derby Lake (Messex, 19'6).

In 1980 and 1981, the Colorado Division of Wildlife and the CDH expressed concern over the potential threat to human health and welfare caused by the consumption of wildlife exposed to potential contaminants in the lakes. In response to these concerns, in 1982 and 1983 Shell and the U.S. Army Engineering Waterways Experiment Station (USAEWES) conducted a follow-up study of pesticide contamination in the south lakes (Myers et al., 1983/RIC 84086R01 Myers & Gregg, 1984/RIC 86192R01). The sampling and analysis phase of this investigation revealed varying concentrations of aldrin, dieldrin, endrin, and mercury in Upper and Lower Derby lakebeds and connecting canals. The highest concentrations were found in the inlet area to Upper Derby Lake (see Appendix SSA-B, Figure SSA-B-2). Based upon these results, recommendations were made to remove contaminated sediments from both Upper and Lower Derby Lakes to reduce concentrations of the contaminants to acceptable levels (Ouimett, 1981; Myers, 1983/RIC 84086R01). USAEWES concluded that Eastern Upper Derby Lake did not require excavation because concentrations of aldrin (1-8 (ppb), dieldrin (4-15 ppb), and mercury (less than 0.1 ppm) were considered very low in comparison to levels in Upper and Lower Derby Lakes (Myers et al., 1983/RIC 84086R01). No excavation activities are known to have occurred since the USAEWES study was concluded.

Studies were conducted in 1984 by the USFWS in Lakes Mary and Ladora for aldrin, dieldrin, endrin, and mercury (USFWS, 1986/RIC 86041R02). All four analytes were found in fish. Concentrations of mercury and dieldrin were found to exceed FDA guideline levels for consumption in some fish collected.



Consequently, sport fishing in both lakes was restricted to catch-and-release fishing (USFWS, 1986/RIC 86041R02; FDA, 1978/RIC 8433R01).

#### 1.3.2.2 Ditches and Overflow Basin

Ditches and overflow basins of the SSA are located in Section 2, Section 3, and south of the South Plants manufacturing complex in Section 1 (Figure SSA 1.1-1). The Section 2 drainage ditch extends approximately 150 ft west of Lake Mary and flows north about 800 ft along the west boundary of Section 2. It then flows 350 ft northwest into an overflow basin in Section 3 (Stout & Abbott, 1982/RIC 83368R01). Total length of the ditch is approximately 1,300 ft. It is 2.2 to 2.7 ft wide and has an estimated area of 3,480 ft<sup>2</sup> (RMACCPMT, 1984a/RIC 84034R01). The ditch drains Lake Mary and is joined along its route by tributary ditches from Lake Ladora and two ditches that channel street run-off and flow parallel to "C" street.

#### Overflow Basin (Site 3-3)

The overflow basin is located in the northeastern quarter of Section 3, west of "C" Street, and at the west end of the drainage ditch discussed above. It is confined by an earthen dam approximately 6 ft high, and retains overflow from Lakes Mary and Ladora (COE, 1984). The area of the overflow basin was originally estimated to be 0.6 acres (RMACCPMT, 1984a/RIC 84034R01), but a review of aerial photographs (Stout & Abbott, 1982/RIC 83368R01) and available maps (RMACCPMT, 1984a/RIC 84034R01) indicates the basin area is about 2 acres, and measures approximately 600 ft long and 150 ft wide.

#### Drainage Ditch (Site 3-2)

The ditch and small tributaries from Lake Ladora were constructed in 1942 to direct overflow from the lake to the overflow basin (Site 3-2). A dam was added to the overflow basin by 1955 (Stout & Abbott, 1982/RIC 83368R01). The overflow basin was a wet area that was initially developed for ducks by the construction of a dike on its western end (Donnelly, 1985b; 1986).

#### Section 1 Drainage Ditches (Site 1-1)

Five ditches located in Section 1, southeast of South Plants, total 7,575 ft in length and have widths ranging from 15 to 48 ft. They encompass a total

area of approximately 2.6 acres (RMACCPMT, 1984a/RIC 84034R01) (Figure SSA 1.1-1). Elevation along the ditches ranges from 5,270 ft msl at the upstream end to 5,255 ft msl at the downstream end. The ditches have historically flowed south from South Plants into Upper and Lower Derby Lake.

Three of the ditches have been abandoned. The ditches have carried surface run-off and industrial cooling system process water from the eastern South Plants area to the Derby Lakes and Lake Ladora since the 1940s. Storm water run-off was and is currently collected in catch basins throughout South Plants and flows through sewers and culverts into the open ditches (COE, 1984). Runoff from contaminated buildings and paved areas in the South Plants area has reportedly contributed chlorinated hydrocarbons and possibly other contaminants to the Derby Lakes via these ditches (Spaine & Gregg, 1983/RIC 83228R01). It is not known how much of the ditch flow originated from the process water system in South Plants versus how much originated as overland flow.

These drainage ditches were initially used to return process water to the lakes system. A piped return line terminated 900 ft east of the ethylene generator building ( Building 433) and discharged into a ditch that carried the water southeast into Upper Derby Lake (CWS, 1945). Process return water was also originally discharged into the ditches, which in turn discharged into Upper Derby Lake (COE, 1984). The "closed loop" system installed in 1964 removed the "East Plants" section of the South Plants from the "lakes circulating process water cooling system." After 1964, the lakes circulating process water system continued to provide water for the power plant condenser (B-326), and the spray pond (B-325) (Shell, 1964; Shell, undated a; Shell, undated b). However, in the mid-1960s, the ditch's use was terminated at about the time that process water was diverted to Lower Derby Lake. The ditch was subsequently filled with dirt.

In 1963, the process water was diverted so that it emptied into Lower Derby Lake instead of Upper Derby Lake. This modification shortened the route and eliminated backflow that was occurring in the original system (Williams, 1963). In 1964, a closed-loop cooling tower system was installed, removing

the lakes from the process water system (Culley, 1971). A diversion ditch was constructed at the northwest end of Lower Derby Lake to connect with a pipe. It drained into Lake Ladora or Sand Creek Lateral (Donnelly, 1963). Between 1963 and 1965 a portion of the ditch system was filled with dirt (Stout & Abbott, 1982/RIC 83368R01).

#### Section 2 Drainage Ditches (Sites 2-1)

A third group of ditches is located in Section 2 and includes the Sand Creek Lateral and its main tributaries (Figure SSA 1.1-1) (Ebasco, 1987j/RIC 87216R05). The ditches currently carry surface drainage into the Sand Creek Lateral from the South Plants manufacturing complex. There are three main areas of tributary ditches (northern, central, and southern tributary ditches).

The northern tributary ditch extends west and northwest from the western portion of the South Plants manufacturing complex and joins the Sand Creek Lateral near the boundary between Sections 2 and 35. Elevations along the northern tributary ditch range from 5,265 ft msl upstream to 5,225 ft msl downstream at the connection with the Sand Creek Lateral.

The central tributary ditches extend from the east-central edge of Section 2, through the South Plants area, to join the Sand Creek Lateral 400 ft north of Lake Ladora. The upstream elevation in the central tributary ditches is 5,270 ft msl and the downstream elevation at Sand Creek Lateral is 5,226 ft msl.

The southern tributary ditches extend across the center of Section 2, south of the South Plants area, and join the Sand Creek Lateral northeast of Lake Ladora. The upstream elevation in the southern tributary ditch system is 5,260 ft msl and the downstream elevation is 5,227 ft msl. Water from Lower Derby Lake can be diverted through a culvert into either Lake Ladora or the Sand Creek Lateral. The ditch system is 24,000 ft long and averages 20 ft wide (480,000 ft<sup>2</sup>).

No specific details of the original construction of these ditches are available. A 1943 erosion control plan (Unauthored, 1943) called for concrete

gutters and ditch paving along the drainage channel immediately south of Buildings 353 through 356, however, the present ditch in this area is not paved.

Prior to 1951, waste from the chlorine plant and other buildings in the South Plants area west of "D" Street and south of December 7th Avenue was intermittently routed through the ditch system into Sand Creek Lateral (Donnelly, 1985a). Shell's operation of the chlorine plant continued until June 1953. Until the Army's use of the chlorine plant during the GB-Brine Project (1956-1957), liquid wastes from chlorine plant operations were discharged to the Sand Creek Lateral through the ditch system (Julius Hyman, 1953b; Streich, undated). Sand Creek Lateral also carried storm water from the buildings and pavements of the South Plants area. In addition, between 1967 and 1974, water that had accumulated in the basement of Building 422 and was thought to contain aldrin, aldrin, bicycloheptadiene, hexachlorocyclopentadiene, dicyclopentadiene, and xylene was pumped into a ditch connected to the Sand Creek Lateral (Augenstein, 1985).

For more details regarding reported spills from South Plants into the ditches, the reader is referred to the following reports: Task 24-Army Spills Sites, Version 3.1, October 1988; Task 2, Site 1-13/2-18, July 1988, South Plants Spills Sites, January 1987; or the South Plants Study Area Report (in progress).

#### 1.3.2.3 Buried Lake Sediments

Excavated lake sediments (or sludge) are buried in two areas within the SSA. One area contains six trenches in which lake sludge is presumed to be buried and is located at the north-central border of Section 11 on RMA, south of Lake Ladora and adjacent to 6th Avenue. The second area is located on the northern border of Section 12, south of Lower Derby Lake (Figure SSA 1.1-1) (Ebasco, 1987/1/RIC 87196R04). The trenches encompass an irregularly shaped area of 14.2 acres, with a general elevation of 5,225 ft msl and a local relief of 20 ft.

#### **Buried Lake Sediments, Section 11 ( Site 11-1)**

This area was reportedly used for disposal of lake sludge dredged from Lake Ladora during 1964, after it was determined that Lake Ladora was contaminated with mercury, aldrin, dieldrin, and endrin (Blackwell, 1973/RIC 81339R20; Donnelly, 1985b). Varying reports indicated that between 4 and 6 inches and 3 and 12 inches of lake sediments were removed in the first stage of dredging (Sheldon & Crabtree, 1965; PMCDIR, 1977/RIC 81266R68). An additional 6 to 24 inches of soil were removed from areas with elevated pesticide concentrations after initial excavation (Crabtree et al., 1964/RIC 84296R04; Sheldon & Crabtree, 1965). It is possible that the trenches received sediments from the Derby Lakes (Witt, 1985), but reports indicate that most of the Derby Lakes sediments were disposed in Section 12. The sludge in Section 11 was covered with 18 inches of clean, uncontaminated topsoil in order to protect vegetation and wildlife from further pesticide exposure (Willis, 1964). The details of the sediment disposal are not available, but aerial photographs show six trenches at the site that probably were filled with the sludge removed from Lake Ladora (Stout & Abbott, 1982/RIC 83368R01).

#### **Buried Lake Sediments, Section 12 (Site 12-1)**

Excavated lake sludge was also buried in the center of the north border of Section 12 on RMA, south of Lower Derby Lake, and between the south side of 6th Avenue and the Rod and Gun Club Pond (Figure SSA 1.1-1) (Ebasco, 1987i/RIC 87196R04). Field reconnaissance during Phase I investigations confirmed that this site encompasses an area of 11.1 acres. This area was presumed to contain soil contaminated with organic and inorganic compounds dredged from Upper and Lower Derby Lakes.

The dredging of the Derby Lakes and Lake Ladora was started in 1964 and completed in 1965. The lake dredging was completed as part of a clean-up action that was intended to stop the annual duck kills, which had occurred in Derby and Ladora Lakes during the water fowl migratory season. The excavation program in the area of the Derby Lakes resulted in the removal of approximately 115,000 cubic yards of soil. This soil was deposited in two areas along 6th Avenue in Section 12. The two areas were separated by a 50 ft wide overflow channel leading to the Rod and Gun Club Pond. The areas on the

west and east banks of the ditch were approximately 4.3 and 7.3 acres, respectively. After the soil was placed in these areas, it was covered with 18 inches of uncontaminated soil and revegetated (Willis, 1964; Quesal, 1965; Donnelly, 1965a; 1965b; 1965c).

#### 1.3.2.4 Excavations, Disposal Sites and Surface Disturbances

There are two areas within the SSA that comprise solid waste disposal sites; a trash dump and a filled-in trench. In addition, several small pits, trenches, storage sites, miscellaneous surface disturbances, and the northern-most Havana Ponds are located within the SSA and were investigated as potentially contaminated areas.

##### Trash Dump (Site 1-12)

A trash dump is located in the central portion of Section 1 on RMA, immediately southwest of the road separating Upper and Lower Derby Lakes (Figure SSA 1.1-1) (Ebasco, 1987a/RIC 87127R03). The dump is rectangular, about 670 by 230 ft, and covers an area of 3.5 acres. The general elevation of the dump is 5,260 ft msl with a local relief of 5 ft. The trash dump was reportedly established in 1978 and may still be used on occasion for disposal of debris. Debris sighted in the dump included steel beams and broken concrete pipe (Way, 1985).

##### Trench (Site 2-5)

A trench is located in the eastern half of Section 2 on RMA, immediately west of "D" Street and the northwestern corner of Lower Derby Lake (Figure SSA 1.1-1) (Ebasco, 1987d/RIC 87216R03). It is rectangular with dimensions of 250 by 30 ft (7,500 ft<sup>2</sup>). The general elevation of the trench is 5,257 ft msl with a local relief of 5 ft.

The trench appears as a rectangular unvegetated area in 1948 to 1980 aerial photographs. Pieces of concrete debris and small metal fragments were discovered on the ground surface near the west side of the trench during a Phase I field reconnaissance of the area in 1985. These fragments may be left from the testing of M-47 bombs north of this area (Stollar et al., 1985).

Based on various information sources, it appears that an oval-shaped ground scar located immediately west of the original disturbed area was excavated to fill sandbags on May 6, 1973, during a flood at RMA (Donnelly, 1985b). This dirt removal created a depression located west of the trench and was surrounded by bulldozer tracks (Way, 1985).

#### **Open Storage Area (Site 2-15)**

An open storage area is located in the southwestern portion of Section 2 (Figure SSA 1.1-1) (Ebasco, 1987t/RIC 88306R04). It was identified from a 1943 aerial photograph. The estimated size of the site is 125 by 125 ft (16,000 ft<sup>2</sup>).

#### **Open Pit (Site 2-16)**

An open pit is located in the southern portion of Section 2, immediately west of Lake Ladora (Figure SSA 1.1-1) (Ebasco, 1987t/RIC 88306R04). It was identified from a 1980 aerial photograph. It measures roughly 30 by 100 ft (3,000 ft<sup>2</sup>). Some sources suggest that this pit may have been created at the same time sludge from Lake Ladora was removed.

#### **Stressed Vegetation (Site 6-9)**

Stressed vegetation in the SSA was identified from a 1980 aerial photograph. Five areas showed dead trees or vegetation possibly killed by contaminated soil or groundwater (Figure SSA 1.1-1) (RMACCPMT, 1984a/RIC 84034R01). Although five separate areas were identified containing stressed vegetation, only the two southernmost areas are within the boundaries of the SSA. These areas of stressed vegetation, located along the southern bank of Eastern Upper Derby Lake, represent low marshland that would periodically flood when Eastern Upper Derby Lake was full (Way, 1985). This flooding may have been the cause of the stressed vegetation.

#### **Northern Havana Pond (11-2)**

Three natural depressions forming the Havana Interceptor Ponds are located in the southwestern quarter of Section 11. An earthen dam was constructed north of these depressions in the early 1970s. The northernmost pond is formed by the earthen berm and was designated by the RMACCPMT as Site 11-2. A

disturbed area within the northernmost Havana Ponds may be where the City of Denver excavated dirt for the construction of a dike for new drainage from Stapleton International Airport.

#### 1.3.2.5 Designated Nonsource Areas

The histories of the designated nonsource areas in the SSA are discussed below by section. RMA activities were not expected to have caused contamination in these areas outside of designated sites.

##### Nonsource Area of Section 1

The nonsource area within Section 1 is located in the south-central portion of RMA (Ebasco, 1987c/RIC 87127R06). Approximately one-half of Section 1 (321.4 acres) has been designated as a nonsource area and generally includes the northeast quarter and south half of Section 1 surrounding Derby Lakes (Figure SSA 1.1-1). The general elevation of the Section is 5,260 ft msl, with a local relief of 20 ft. There are no buildings or structures within the nonsource area of Section 1. No indication has been found in aerial photographs or RMA records to suggest that this area experienced identifiable surface disturbance or was used for liquid or solid waste disposal.

##### Nonsource Area of Section 2

The nonsource area within Section 2 is that portion of Section 2 outside of RMACCPMT-designated contaminant site boundaries (Figure SSA 1.1-1) (Ebasco, 1987e/RIC 87127R08). It is located southwest of the central portion of RMA, south of December 7th Avenue, north of 6th Avenue, east of "C" Street, and west of "D" Street. The nonsource area of Section 2 considered to be within the SSA is the area south of the Sand Creek Lateral and all of the area approximately 500 feet south of the east-west running gravel road just south of Building 362 and north of Sand Creek Lateral. The SSA's portion of the nonsource area of Section 2 comprises approximately 275.5 acres. The general elevation of the nonsource area in Section 2 ranges from 5,220 to 5,265 ft msl. Major structures include a swimming pool (Building 368), a water pump station (Building 371), a reservoir (Building 372), a chlorination station (Building 372A), a water treatment plant (Building 374), an officer's station (Building 373), a garage (Building 373b), a Community Club (Building 383), and a community club storage building (Building 383A).



The water treatment plant (Building 374), built in 1942, is in the southeastern quarter of Section 2, not far from "D" Street. Operating charts from 1943 (Unauthored, 1943) indicate the use of an alum solution in the treatment plant. As of 1950, Building 374 was being used by the Colorado State Game Commission for grain storage (COE, 1950a).

Buildings 368, 371, 372, 372A, 373, 373b, 383, and 383A are located to the north of Lake Mary in Section 2. Building 372, a 1,000,000 gallon water reservoir constructed in 1942, is a roofed, concrete-lined earthen basin (Unauthored, 1944; COE, 1950). This covered water reservoir acts as a backup supply at the RMA for the City of Denver potable water main services. During a backup operation, the water from the reservoir is supplied to nearby pump Building 371, and from there is pumped into the potable water distributing system through a bypass valve. In times of high usage, the potable water system could also be connected to the process water system to supplement the industrial areas' water needs. Other than potable water, electricity is the only other utility that services Building 372. The only potential chemical contaminant used in the reservoir and potable water system is chlorine. No evidence of contamination of the potable water supply has been found, and the reservoir has been classified as uncontaminated. The swimming pool, Building 368, was built in 1956 along with a bath house and filter room (Unauthored, 1956; Blackwell, 1973/RIC 81339R20). A gravel parking lot was constructed east of the pool and later topped with asphalt (Unauthored, 1958). The pool is still in use. The family quarters in Building 373 were still occupied as of 1973 but vacated by late 1985 (Blackwell, 1973/RIC 81339R20; Heim, 1985). Building 373B is a garage that is currently in use. Aerial photographs show that the Officer's Club, Building 383, was constructed between 1971 and 1974 (Stout & Abbott, 1982/RIC 83368R01).

Historical data do not indicate that observed ground scars in the nonsource areas of Section 2 were related to the production or disposal of potential contaminants. No spill incidents or waste disposal operations are known to have occurred within the nonsource area. However, application of dichlorodiphenyltrichloroethane (DDT) for mosquito control may have taken place around the lakes or the picnic area during the 1950s and 1960s (Mitchell, 1986).

#### **Nonsource Area of Section 7**

The area of Section 7 that is not included within RMACCPMT-designated contaminant site boundaries has been designated as the nonsource area of Section 7 (Figure SSA 1.1-1) (Ebasco, 1987q/RIC 87336R13). This section has historically been used as part of the RMA buffer zone. It is bordered by 6th Avenue to the north, "F" Street to the east, 5th Avenue to the south, and "E" Street to the west. Only that portion south and west of the Highline Lateral lies within the SSA (approximately 229.6 acres). The Highline Lateral Canal diagonally bisects the nonsource area of Section 7, from the southeast corner to the northwest corner. The canal initially was called the Derby Canal and was used prior to 1942 as an irrigation ditch (RMA, 1945). During the initial construction of RMA, the Highline Lateral was rebuilt and modified so water from the Highline Canal, located south of RMA, could be diverted to the lower lakes in Sections 1 and 2 (RMA, 1945). The Highline Lateral is 6 miles long with 4.5 miles located off RMA (RMA, 1945). The amount of water flowing in this lateral depends on precipitation and local water rights (Smith, 1982).

No chemical agent, commercial chemical, or anticrop agent has been manufactured or stored in the nonsource area of Section 7 within the SSA (Blackwell, 1973/RIC 81339R20). After the 1960s, regular sprayings of malathion may have occurred in the section during the summer months to control mosquitoes (Lynes, 1985). There are no buildings or structures in this nonsource area.

#### **Nonsource Area of Section 11**

Excluding the buried lake sediment and two southernmost Havana Ponds, Section 11 on RMA is not included within RMACCPMT-designated contaminant site boundaries and has been designated as a nonsource area (Figure SSA 1.1-1) (Ebasco, 1987l/RIC 87216R10). This area is bordered by 6th Avenue to the north, "D" Street to the east, 5th Avenue to the south, and "C" Street to the west. The South Gate and guardhouse of RMA are in the southwestern corner of the section (PMCDIR, 1977/RIC 81266R68). The nonsource area within Section 11 encompasses 626.2 acres and the elevation ranges from 5,230 to 5,275 ft msl.

These portions of Section 11 have no reported history of chemical contamination. Section 11 has been part of RMA since its original construction in 1942. Section 11 was used by the Rod and Gun Club for recreational activities, which included hunting with lead shot (Ebasco, 19871/RIC 87216R10; Mack, 1987). There are five picnic areas in the eastern half of the section (RMACCPMT, 1984a/RIC 84034R01). The two southernmost Havana Ponds are located in the southwest corner of Section 11 (Figure SSA 1.1-1). Two drainage channels enter the southernmost Havana Pond at its southwest corner (Donnelly, 1985b). The Havana Street Interceptor, a concrete-lined flume constructed in 1973, enters the west edge of the pond and brings surface run-off northward from the Montbello industrial complex. The interceptor is unlined where it enters the pond and serves as a ditch to drain Stapleton airfield to the Havana Street Interceptor Ponds (Rock, 1985). An unlined drainage channel, the Peoria Interceptor, drains the industrial complex south of RMA and enters the basin at its southern end (DOJ, 1986). The largest pond (southernmost) has a high water level of 5,252 ft msl and a capacity of 320 acre-feet (DOJ, 1986).

#### **Nonsource Area of Section 12**

The nonsource area within Section 12 covers approximately 94 percent of Section 12 on the southern edge of RMA (Ebasco, 1987m/RIC 87216R11). This area lies outside the boundaries of the buried lake sludge site and the Rod and Gun Club Pond and is bordered by 6th Avenue to the north, "E" Street to the east, 5th Avenue to the south, and "D" Street to the west (Figure SSA 1.1-1). This nonsource area encompasses 605.8 acres and the elevation ranges from 5,245 to 5,290 ft msl.

In addition to being used by the Rod and Gun Club, the nonsource area of Section 12 has been the site of picnics, of Boy Scout and Girl Scout activities, and has been part of the buffer zone for RMA operations (Blackwell, 1973/RIC 81339R20). The Rod and Gun Club reportedly planted some areas with crops such as corn and wheat to serve as game forage (Donnelly, 1985a; Stout & Abbott, 1982/RIC 83368R01). In late 1969, Perl-Mack Enterprises Company of Aurora, Colorado constructed the unlined Uvalda Street drainage ditch. The ditch crosses Section 12 to permit run-off from the Montbello residential area to drain northward to Lower Derby Lake (DOJ, 1986).

During flood conditions in 1973, a ditch from Lower Derby Lake to a low swampy area in the north-central part of Section 12 was enlarged to alleviate pressure on Lower Derby Lake (Unauthored, 1973). As a result, the low area, which occasionally filled with water, became a more permanent water-containing feature and was named the Rod and Gun Club Pond (Donnelly, 1985b). The ditch draining Lower Derby Lake overflow was enlarged again in 1982. The ditch was cleaned as necessary, and dirt and debris were stockpiled in the old fill. The berm on the south side of the Rod and Gun Club Pond was also opened to allow for overflow (Berry, 1982).

By 1984, the U.S. Army Reserve had established an Organizational Maintenance Shop/Area Maintenance Support Activity in the southwest corner of Section 12. This area was to be used for vehicle maintenance (COE, 1984; Mitchell, 1986).

In February 1983, a charge of flash powder and a possible land mine were discovered by a group of Boy Scouts in the area of the rifle range (McNeill, 1983a; McNeill, 1986). At that time, it was believed these two items were a result of Army Reserve activities at the rifle range. A team of Technical Escort personnel searched the area for additional items but nothing was found (McNeill, 1986).

DDT, a pesticide not manufactured at RMA by Hyman, was sprayed around picnic areas, lakes, waterways, and ditches on RMA during mosquito season by the Army (Mitchell, 1986). It is possible that the picnic areas, ditches, and ponds in Section 12 were included in these sprayings.

#### 1.4 GEOLOGY

An investigation of the SSA geology is critical in defining the nature and extent of the geological media containing contaminants and is important for the understanding of these media as contaminant transport pathways. An overview of the SSA geology is presented below, which is followed by a more detailed description of the lithology and stratigraphy of areas significant to the contamination assessment.

Soils, sediments, and two geologic units are being investigated in the SSA in connection with the suspected presence of contaminants contained in these media and the potential for migration of contaminants through them. Only the two uppermost geologic units are investigated in this section of the report because of their potential for contact with contaminants. These include the surficial unconsolidated alluvium and the Denver Formation bedrock, which consists largely of ancient fluvial and deltaic deposits (May, 1982/RIC 82295R01). Figure SSA 1.4-1 presents a general stratigraphic column for these units. In the subsections that follow, the geologic character of the soil zone, lake bottom sediments, alluvial sediments, and Denver Formation are discussed in terms of key areas in the SSA. These areas are known or are suspected to contain contaminants; included are the lakes, the boundary between South Plants and the SSA (the boundary interface), and the ditch system. Representative cross-sections, constructed from well and borehole data in the key areas, are used to support the discussion of the geology and its relationship to contamination distribution and migration.

#### 1.4.1 Soils

The thickness of the developed soil zone in the SSA typically extends to a depth of 59 to 70 inches (USDA-SCS, undated; Walsh, 1988). The shallower reported depths have characteristics of disturbed soils, including fill material varying in thickness from 4 to 17 inches, over truncated horizons of natural soils to a depth of 59 inches. Natural soils in the SSA are classified in the Bresser-Truckton and Bresser-Satanta Associations (Walsh, 1988). These soils typically formed in medium to coarse textured alluvium, which were later affected by eolian deposits. Typical soils in these two associations range from nearly level to strongly sloping and are well-drained. Textures vary in the profile from loamy sands, sandy loams and loams on the surface; to sandy clay loams, sandy loams, and clay loams in subsurface intervals.

Four soil series, one subgroup and one undifferentiated group (consisting of fill materials, sediments, soils, and structures), comprising 13 mapping units, occur in the SSA (Walsh, 1988). The specific locations of the mapping units are shown in Figure SSA 1.4-2. The major soil series in the SSA are the

Bresser sandy loams and Truckton loamy sand. Other minor soil series include the Santana and Weld loams and Bresser-Santana Association. Aquic Haplustolls occur along alluvial terraces, floodplains, drainages, and depressions but are not very extensive. Specifically, these soils occur adjacent to the lakes and along portions of the Havana Ponds and Highline Lateral. In addition, approximately 6 percent of the soils in the SSA are disturbed and vary in texture from loams to sands.

Physical, hydrologic, and chemical properties of key soil series and subgroups that influence contaminant migration in the SSA are summarized in Tables SSA 1.4-1 and SSA 1.4-2. These representative characteristics are summarized from agronomic testing of soil cores collected within the SSA by MKE, as well as background information provided by the U.S. Department of Agriculture Soil Conservation Service (USDA-SCS, 1967; USDA-SCS, 1974/RIC 81266R54; USDA-SCS, undated). Texture, clay content, and hydraulic conductivity tend to vary with depth as well as between soil series. Sandier soils, such as the Truckton, have low clay components, retain less water, and have fairly low bulk densities, thus increasing the infiltration potential of contaminants. Cation exchange capacities tend to be highest in the soils containing argillic or clay horizons. Typically, this is most notable below a depth of 12 inches. The Weld and Santana series and the Aquic Haplustolls contain clayey soils with consequentially high cation exchange capacities. Truckton soils have the lowest cation exchange capacities. The hydraulic conductivity of the key soil series range from slow to rapid and depend greatly on texture and slope gradient. Most soils are well drained, except for the Aquic Haplustolls, which receive run-off and may be saturated for extended periods. The Aquic Haplustolls lack an argillic horizon and may be mottled below a depth of 12 inches.

Bresser, Santana, and Truckton soils contain calcareous zones at depths from 8 to over 57 inches. Corresponding soil pHs of the SSA soils range from slightly acidic (6.2) to strongly alkaline (9.0) and increase with depth. Some intervals may contain up to 40 percent calcium carbonate equivalent (lime). The shrink-swell potential of most of these soils is low to moderate (with occasional high zones), which improves the propensity for increases in

permeability, depending on moisture content. Erosion hazard varies, dependent upon slope and vegetation cover.

Most of the soils in the SSA have low organic carbon content, varying from 0.1 percent to about 2.0 percent. The highest organic matter content occurs in the surface horizons of both upland soils and in lake sediments. The sodium absorption ratio values for most soils in the SSA indicate that the soils are nonsodic and would not limit plant growth. The exception is in the Aquic Haplustoll soils, where the lack of adequate drainage has increased salt accumulation potential. Subsequently, the potential for breakdown of soil structure is enhanced under these conditions. The collapse of soil aggregates may cause a subsequent decrease in infiltration and hydraulic conductivity and an increase in run-off to adjacent areas.

There is wide variability in physical, hydrologic, and chemical characteristics of disturbed areas near industrial or other types of structures. In general, the original surface horizons were removed and replaced with fill materials of unknown origin. Predominant textures of disturbed soils vary from loamy sands and sandy loams to loams. The sandier disturbed lands have properties resembling Bresser and Truckton soils, while the clayey loamier disturbed soils resemble Santana soils, all of which occur naturally in the SSA.

#### 1.4.2 Lake Sediments

As part of the Task 20 Phase II Lower Lakes investigation, bottom sediments were collected from Upper and Lower Derby Lakes, Eastern Upper Derby Lake, Lakes Ladora and Mary, and Rod and Gun Club Pond. Samples were analyzed for physical and chemical characteristics useful in estimating contaminant partitioning between the sediments and interstitial water and measurements of potential bioaccumulation. The results of these analyses are presented in Table SSA 1.4-3.

A review of the data from Task 20 Phase II investigations conducted in 1987, as well as 1982 studies conducted by the USAEWES (Myers et al., 1983/RIC 84086R01), indicates that sediment thicknesses in the Derby Lakes, Lake

Ladora, and Lake Mary range from 1 to over 3 ft. Much of this sediment may have been deposited over a 23 year period following the completion of dredging activities in the Derby Lakes and Lake Ladora (Kenney, 1965). A more thorough account of the dredging activities is presented in Section 1.3.

Studies by Bergersen and others (1984/RIC 84142R01) report that sedimentation rates in Lower Derby Lake averaged 1.91 centimeters per year (cm/yr) and 1.23 cm/yr in Lake Ladora. If this rate of deposition were constant, one-third to one-half of the sediment observed would have been deposited since the time of dredging.

Textures of the materials are variable, with lenses of silty sands interbedded with silts and clays having low organic content. Gravels and peats occur in isolated instances throughout the lakes region sediments. The pH values of the sediments are more variable than those of upland soils, perhaps as a function of organic matter content. The highest organic content (2.6 percent) is found in the shallowest sediments. Redox potentials found in the lake sediments are typical for wet to moist soils (Bohn et al., 1985). The most organic matter is found in the surface sediments of Upper and Lower Derby Lakes. Electrical conductivity (EC) fluctuates greatly and may reflect a high concentration of soluble salts in the sediments. The highest EC values correspond to the samples with alkaline pH values.

#### 1.4.3 Alluvium

Because of its proximity to the surface and surface contaminant sources, the alluvium is investigated. The nature of the alluvium is discussed below.

The unconsolidated Quaternary alluvium in the SSA (Figure SSA 1.4-3) was deposited by local tributaries; however, some of these sediments have been reworked and redeposited by wind. Although most of the sediments are fluvial in origin, they represent a mixture of eolian, alluvial, and colluvial deposits. In this report, the term "alluvial" will represent all Quaternary unconsolidated sediments present in the vicinity of the SSA regardless of their mode of deposition.



Various episodes of sedimentation and erosion occurred during the accumulation of the alluvium resulting in several sediment types in the study area (May, 1982/RIC 82295R01; MKE, 1988). Clayey and silty sands are the most abundant sediments. Less permeable silty, sandy clays are also common. These clays generally occur as discrete lenses or discontinuous layers but can also occur as continuous layers. Relatively thick sands are also common in the SSA but may also form thin lenses and discontinuous layers.

Where sands are mapped as continuous layers, they may act as preferential pathways for the groundwater within the alluvium and possibly into the underlying Denver Formation. Gravels and gravelly sands are the least common sediments present, and usually occur at or near the base of the alluvium as discontinuous lenses. Although the gravels are not common, their potential for high permeabilities and proximity to the Denver Formation make them a probable pathway for groundwater to flow between the alluvium and the bedrock sands.

The thickness of the alluvium in the SSA ranges from less than 5 to approximately 100 ft (Figure SSA 1.4-4). The alluvium tends to thin to the north and south, and thicken in the central portion of the study area where the downward slope of the bedrock surface increases rapidly. In general, the alluvium is thicker in the bedrock channels. The erosion left bedrock highs in the north-central portion of the SSA toward South Plants and cut a channel through the central portion of the area. This east-west trending paleochannel is referred to as the Irondale Gulch paleochannel. The continuity of the alluvial sediments is difficult to define because of their fluvial nature. In general, these sediments tend to be lenticular, but are probably truncated where the bedrock surface steps up to the north and away from the channel.

Cross-sectional perspectives of the lakes, ponds, boundary interface, and the ditch system are referenced to support these descriptions. The relative locations of the cross-sections are presented in Figure SSA 1.4-5. The cross-sections themselves are presented as plates in the back of this report.

#### **Lake Ladora and Western Portion of Lower Derby Lake**

The alluvium beneath Lake Ladora along the western portion of Lower Derby Lake predominantly consists of clean sand and silty, clayey sand (Plate SSA 1.4-1). Along the western edge of Lower Derby Lake, clean thick sands occur with discontinuous lenses of silty clayey sands and one minor clay layer (Cross Section SS1-SS1'). It is important to note the absence of clay layers in the alluvium along the western portion of Lower Derby Lake. This absence may promote communication between the potentially more permeable alluvial material (sands and gravels) and the underlying Denver Formation. The thickness of the alluvium varies from approximately 10 ft north of Derby Lakes to approximately 60 ft south of the lake where the bedrock surface drops off abruptly to a bedrock channel. Thick silty, clayey sand is the predominant unit below and to the south of Lake Ladora. Clay layers are more abundant toward the southern end of these lakes and appear to be relatively thin and lenticular (cross-sections SS2-SS2', SS3-SS3')

The area near Lakes Mary and Ladora contains one of the thickest portions of alluvium where it fills a bedrock paleochannel, called the Irondale paleochannel. The alluvial thickness reaches 100 ft near the west-central edge of the study area. East of Lake Ladora, the alluvium thins to approximately 20 ft.

#### **Upper and Lower Derby Lake**

Clean sands and clayey silty sands comprise the alluvial material near and at the bottom interface of Upper and Lower Derby Lake (Plate SSA 1.4-2). As is expected in a fluvial environment, the cleaner, coarser sands are positioned below the clay and silt-rich sands at this interface (cross-sections SS5-SS5', SS7-SS7', SS8-SS8'). North and south of the Derby Lakes these sands are found deeper in the alluvial section and appear to be discontinuous to the east and west (cross-sections SS4-SS4', SS6-SS6'). South of the lakes, gravels are found lower in the section, and silty, clayey sands become the most common material. A clay layer appears throughout much of the Derby Lakes area, although its lateral continuity is not well defined.

### **Rod and Gun Club Pond and Sludge Pile**

In this area, the alluvium ranges in thickness from 30 to 80 ft. Silty sands compose the upper 20 to 30 ft over much of the area, and a 10 to 20 ft thick clay unit, can be traced across the area under the silty sand. The lowermost unit is also a silty sand that becomes a coarser sand to the east.

### **Boundary Interface Area**

The boundary interface area (Plate SSA 1.4-3) originates at South Plants and extends southeasterly into the north-central portion of the SSA toward Lake Ladora. Clayey, silty sands and inorganic silts comprise most of the alluvium in the northern part of this area (cross-sections SS10-SS10', SS11-SS11'). The alluvium becomes sandier and potentially more permeable toward Lake Ladora (cross-section SS9-SS9'). Very little clay is encountered anywhere in this area. North of Lake Ladora the alluvium is approximately 30 ft thick. It thins to 5 ft or less toward South Plants, over a distance of 1,000 ft.

### **Ditch System**

There are three ditches in the SSA that are represented in cross-sections SS12-SS12', SS13-SS13', and SS14-SS14' on Plate SSA 1.4-4. These cross-sections were constructed with shallow borehole data from the ditches. Deeper information was extrapolated from intersections with cross sections constructed between wells on either side of the ditches. The alluvium in the ditch system is composed of inorganic silty, clayey sands underlain by silty and sandy clays. In the extreme northwestern portion of the study area, both of these units are underlain by a thicker, potentially more permeable sand. This sand also appears in an area where the alluvium thickens to about 30 ft (cross-section SS14-SS14'). The alluvium thins to less than 5 ft in South Plants and in the north portion of the study area (cross-section SS12-SS12').

#### **1.4.4 Denver Formation**

The bedrock unit underlying the alluvial sediments is the Denver Formation. Within the SSA, the bedrock surface is topographically highest near South Plants. In this area, it is approximately 1 ft below the ground surface. The bedrock surface generally dips away from South Plants and is cut by the Irondale Gulch paleochannel that runs through the central portion of the study

area (Figure SSA 1.4-6). Some of the Denver Formation sands that are present in the bedrock high may subcrop. These subcrops may place a permeable layer of the Denver Formation in contact with permeable alluvial sediments and may act as a potential groundwater conduit between the alluvium and bedrock.

Because of its potential interaction with surface contaminants through these or other conduits and because of its proximity to contamination sources at or near the surface, the Denver Formation is discussed in more detail below.

The Denver Formation is fluvial in origin but contains volcanoclastic sediments as well. In the SSA, the Denver Formation contains a variety of lithologies, including thick channel sands, thinner discontinuous clays, sand and silt lenses, lignitic intervals, massive claystone intervals, and volcanoclastic units. From well data, thick sequences of claystone and some mudstone in the Denver subcrop near the northern perimeter of the SSA along the bedrock high. These clays and muds contain lenses or discontinuous layers of more permeable strata, mostly sandstone but some siltstone. Volcanoclastic sediments subcrop along the northeastern portion of SSA (southeastern edge of South Plants) above the claystone sequences. Well log data indicate that much of the upper Denver Formation is fractured; the extent of the fracturing, however, is not well defined.

A mixture of lithologies is found below the sloping bedrock south of South Plants. Although claystone beds thin in this area, they are the most common lithology. Lignite, sandstone, and siltstone zones generally underlie the claystones. These zones include sand-rich intervals and lignite beds that serve as marker beds, distinguishing the different sand intervals. The most prominent lignite bed in this area is referred to as the "LA." Sandstones and siltstones were most likely deposited in the fluvial environments that covered the area during sedimentation of the Denver Formation (May, 1982/RIC 82295R01; MKE, 1988). They include elongate, channelized deposits that extend a few tens of feet across, as well as sheet-like bodies that may have spread over several hundred feet (Walker & Cant, 1979). Although data in the Denver Formation are sparse, they provide sufficient detail to gain an understanding of bedrock geology. Cross-sections made from all available well data in the

key areas are used to project zones in the Denver Formation (Plates SSA 1.4-1 through 1.4-4). These projections only show trends and interpretations of the geology and should be used accordingly.

The topographic surface of the Denver Formation is shown in Figure SSA 1.4-7. The different lithologies shown in this figure have been named according to their vertical positions relative to the prominent lignite bed (the "LA"), mentioned above. This bed is used as a marker bed and is traceable within the Denver Formation under a large portion of the RMA. Lignite unit LA is characteristically black, hard to brittle, and breaks in a blocky to platy manner. A zone of varying proportion of claystone and sandstone above LA is referred to as "A" sandstone. This zone is a major channel sand deposit averaging approximately 40 ft in thickness.

Near South Plants, in the northern portion of the SSA, the uppermost Denver Formation tends to consist of two units: volcanoclastic (VC) deposits and a mixture of lithologies which have been defined as a volcanoclastic equivalent (VCE) zone.

A more detailed discussion of the Denver Formation for specific areas within the SSA is given below.

#### **Lake Ladora and the Western Portion of Lower Derby Lake**

Bedrock along the northeastern edge of Lake Ladora is largely claystone with discontinuous sand and silt stringers (Plate SSA 1.4-1). These stringers may extend and subcrop below Lake Ladora and along the western edge of Lower Derby Lake; their lateral extent, however, is not well defined west of Lower Derby Lake where claystone and siltstone layers subcrop beneath the alluvium. (cross-section SS1-SS1'). Thick sequences of channel sands are more common south and east of Lakes Ladora (cross-section SS2-SS2'). One of these sands subcrops near the southern extension of Lake Ladora and may be in communication with an alluvial sand (cross-section SS3-SS3'). These sands are underlain by the lignite A (LA) unit that may subcrop west of the lakes where the bedrock surface drops off.

### **Upper and Lower Derby Lakes**

Toward the northern end of both lakes, there exists up to 30 ft of volcanoclastic sediments (Plate SSA 1.4-2, cross-section SS4-SS4'). The bedrock surface drops off beneath the lakes and intersects more claystone as well as lignitic intervals and sandstones (cross-sections SS6-SS6', SS7-SS7', and SS8-SS8'). There may be open communication between the potentially permeable channel fill material of the alluvium and a thick sandstone of the Denver Formation below the western portion of Lower Derby Lake. South of the lakes, claystone is the dominant lithology near the bedrock surface.

### **Rod and Gun Club Pond and Sludge Pile**

Nearby wells show claystone subcropping throughout the area. Thin discontinuous sandstone and siltstone zones appear in the wells but probably do not subcrop.

### **Boundary Interface Area**

In the vicinity of South Plants Study Area, toward the north-central portion of the SSA, the bedrock surface forms a broad, south trending, gently dipping ridge (Plate SSA 1.4-3). Weathered claystone subcrops along the crest of the ridge in most wells (cross-sections SS9-SS9' and SS10-SS10'). Where the bedrock surface drops off to the southwest, however, a potentially permeable lignite/sandstone sequence may subcrop or intersect with alluvial sediments. If the sandstone intersects with similar alluvial material, there may be open communication between the alluvium and the Denver Formation. This sequence is underlain by a potentially less permeable claystone. Southeast of the boundary interface, toward Lower Derby Lake, siltstones and claystones are the primary subcropping units (cross-section SS11-SS11'). Thick channel sandstones are found deeper in the Denver Formation throughout this area.

### **The Ditch System**

Although the geology and lithology of the Denver Formation is extrapolated from wells near the ditches, cross-sections SS12-SS12', SS13-SS13', and SS14-SS14' follow regional trends (Plate SSA 1.4-4). For example, the Denver Formation forms a high in the northern part of the SSA, and in South Plants, where it is less than 5 ft from the surface. Away from South Plants to the

west, south, and southeast, the bedrock surface tends to drop off to the Irondale Gulch paleochannel that is approximately 30 ft below the surface. A relatively impermeable claystone is the most common lithology at the bedrock surface. However, volcanoclastic deposits subcrop along the northeastern edge of the SSA, north of Upper and Lower Derby Lakes, and may be in contact with other Denver Formation sediments in this area. Thin sandstone layers are also common and are very close to the bedrock surface in the extreme northwest ditch above Lake Ladora.

## 1.5 HYDROLOGY

The following discussion regarding hydrology in the SSA focuses on characteristics of surface water and groundwater that may affect migration of potential contaminants.

The SSA is characterized by a system of lakes and ditches that store and direct most surface water that enters or falls upon the area. The following discussion is divided into five sections on surface water, vadose (unsaturated) zone, groundwater, alluvial/Denver aquifer interaction, and surface water/groundwater interaction.

### 1.5.1 Surface Water

Surface drainage of the SSA is primarily controlled by the Irondale Gulch drainage basin and to a minor extent by the First Creek drainage basin. These basins drain approximately 56 square miles, 27 of which are on RMA (COE, 1983/RIC 84066R01). (Figure SSA 1.5-1) The general drainage direction for Irondale Gulch and First Creek is northwest, ultimately discharging into the South Platte River, approximately 3 miles northwest of RMA. Irondale Gulch and First Creek basins are described more completely in the following subsections.

#### 1.5.1.1 Irondale Gulch Drainage Basin

Irondale Gulch drains most of the SSA and contains the major lakes of the area. The basin encompasses the area directly southwest of First Creek basin. It covers an area of 11.5 square miles upstream of RMA and 18 square miles at the RMA northwest boundary (COE, 1983/RIC 84066R01). The average

estimated run-off into the entire Irondale Gulch drainage system for the 1971-1979 period is 923 acre-feet per year (Resource Consultants, 1982/RIC 82096R01). Drainage begins near the intersection of Interstate 70 and East Colfax Avenue in Denver; Interstate 70 forms the southwest boundary for most of the Irondale Gulch basin. Within RMA boundaries, Irondale Gulch is very poorly defined and lacks channelized flow. Irondale Gulch is characterized by a series of three major and several minor reservoirs (lakes), as well as a number of topographic depressions and ditches that store and channel water only during times of high precipitation events.

The remaining discussion of the Irondale Gulch basin describes those features characterizing the surface hydrology of the SSA. The features within the study area and adjacent areas that affect the SSA include the following: ditches that originate off-post, ditches that originate on-post, and on-post lakes. Lake storage capacities, lake water quality, flood potential, and water balance within the RMA area included in the Irondale Gulch basin are also discussed.

#### Ditches that Originate Off-Post

Water collected from off-post areas is directed to RMA by a number of man-made ditches. These ditches (or canals) drain the adjacent areas in the following manner:

1. The Sand Creek Lateral enters RMA at the middle of the western border of Section 11 and winds through RMA, potentially receiving discharge from Lower Derby Lake (Figure SSA 1.2-2), the Havana Ponds, and the western portion of South Plants.

The Sand Creek Lateral enters the First Creek drainage in Section 25, just northeast of the North Plants manufacturing complex. No data on the volume of Sand Creek Lateral flow were available.



2. The Havana Street Interceptor enters RMA in the southwest corner of Section 11 (Figure SSA 1.2-2) and brings storm water (via storm sewer systems) into the Havana Ponds (COE, 1983/RIC 84066R01). An estimate of flow through the drainage is 1,300 acre-feet per year (ESE, 1988a/RIC 88173R06). This relatively large flow may be attributed to increased urbanization upgradient of the Interceptor.
3. The Peoria Interceptor enters Section 11 approximately 1,500 ft east of the Havana Street Interceptor (Figure SSA 1.2-2) and directs storm water into the Havana Ponds. An estimate of street run-off brought onto the RMA by the Peoria Interceptor for 1985-1987 is 152 acre-feet per year (ESE, 1988a/RIC 88173R06).
4. The Uvalda Street Interceptor enters RMA at the middle of the souther border of Section 12 (Figure SSA 1.2-2). It channels storm water from Montbello Basins (off-post, south of the SSA) and discharges into Lower Debry Lake (COE, 1983/RIC 8406R01). Flow of 265 to 350 acre-feet per year is channelled onto RMA by the UValda Street Interceptor (Resource Consultants, 1983/RIC 82096R01).
5. The Highline Lateral enters RMA in the southwestern corner of Section 8 (Figure SSA 1.2-2), channels overland flow irrigation water from the Highline Canal, and discharges into Upper Derby Lake. It is dry except during late spring and summer. Flow into RMA varies widely, Based upon RMA demand.

#### Ditches That Originate On-Post

Several ditches in Section 1 were constructed to direct South Plants process water and run-off into the lakes system. The ditches originally consisted of two sets, one discharging to Upper Derby Lake and the other either to Lower Derby Lake or directly into the Sand Creek Lateral and Lake Ladora. The latter ditch bypassed Lower Derby Lake through a submerged and buried pipe to a culvert that fed into either the Sand Creek Lateral or Lake Ladora. Although not part of the South Plants ditch system, the ditch south of Lower Derby Lake is related in that it directs overflow from the lake to the Rod and

Gun Club Pond. In 1963, the series of ditches connected to Upper Derby Lake was closed; the series of ditches connected to Lower Derby Lake then carried all process water and run-off. In 1964, a closed-loop cooling tower system was installed to replace the lakes and ditches as a cooling system. Since that time, the ditches have carried only surface run-off (Ebasco 1987t/RIC 87196R01).

In Section 2, three main ditches direct run-off from the western edge of South Plants directly into the Sand Creek Lateral to the west. A separate ditch receives overflow from the western edge of Lake Ladora and directs the flow south of Lake Mary where it ultimately drains into the overflow basin of Section 3 (See Section 1.3).

#### Lakes System

Lakes of the Irondale Gulch drainage system within the SSA are Upper Derby Lake (including Eastern Upper Derby Lake), Lower Derby Lake, Lake Ladora, Lake Mary, Rod and Gun Club Pond, and the Havana Ponds (COE, 1983/RIC 84066R01).

Upper Derby Lake, the northernmost lake in the series, receives run-off from the Highline Lateral and ditches from the South Plants area. The lake straddles "E" Street, with one portion in Section 6 (Eastern Upper Derby Lake) and the other in Section 1. Upper Derby Lake overflow channel (Figure SSA 1.2-2) drains the uppermost portion of the lake during periods of high water, directing overflow to the northeast toward First Creek. Although Upper Derby Lake has been dry in the recent past, it currently contains water that entered the lake due to protracted diversion of rainwater run-off in the spring and fall of 1988.

Lower Derby Lake is a permanent water body that experiences periodic annual depth fluctuations. Located entirely in Section 1, the lake receives overflow from Upper Derby Lake during times of high water. It also receives storm water run-off from the Uvalda Street Interceptor and receives run-off from South Plants. Lower Derby Lake releases overflow to the Rod and Gun Club Pond to the south and downstream to the Sand Creek Lateral or Lake Ladora. Lower Derby Lake currently contains water.

Lake Ladora, located in Section 2, is a permanent water body that receives water from Lower Derby Lake (via Sand Creek Lateral) and from South Plants run-off. At one time, water was pumped from Lake Ladora for process water cooling, irrigation, firefighting, and use in steam production. It is no longer used for crop irrigation purposes but is used to water lawns. According to personal communication (1988) with Stearns-Roger, Inc., Lake Ladora water is still available for firefighting purposes but is discouraged from use in steam production because of water hardness. Overflow exits Lake Ladora through a ditch that flows around the southern edge of Lake Mary, then north around the west side along "C" Street, crosses under "C" Street into Section 3, and then flows about 1,000 ft west where channelized flow terminates at an earthen dam. The drainage containing the earthen dam flows into the Western Study Area through a loosely defined series of topographic depressions.

Lake Mary, located in the western portion of Section 2, receives surface water only from drainage northeast of the lake. Any outflow moves into the previously described ditch that drains Lake Ladora into Section 3. Lake Mary currently contains water.

Rod and Gun Club Pond, situated in the north-central portion of Section 12, receives overflow from a ditch leading south from Lower Derby Lake through an area of buried lake sludge. No outflow exists for Rod and Gun Club Pond. Rod and Gun Club Pond currently contains a minimal amount of water.

The Havana Ponds, located in the southwest quarter of Section 11 collect storm water run-off entering via the Peoria and Havana Street Interceptors (Figure SSA 1.1-2). During times of high water, they may release water to the Sand Creek Lateral.

#### Lake Storage Capacities

The reservoirs of the Irondale Gulch basin (Upper and Lower Derby, Ladora, Mary, Rod and Gun Club, and Havana Ponds) have a combined storage capacity of 3,000 acre-feet (COE, 1983/RIC 84066R01) at embankment crest.

The following are lake volumes from October 1985 through November 1987.  
(Water Remedial Investigation Report, Ebasco, 1989/RIC89067R08)

	<u>Havana</u> <u>Pond</u>	<u>Upper and</u> <u>Lower Derby</u> <u>Lakes</u>	<u>Lake</u> <u>Ladora</u>
Maximum	68.2	662.8	379.3
Volume	(July 1987)	(Oct. 1985)	(Dec. 1985) (Feb. 1986) (Mar. 1986)
Minimum	4.3	425.5	318.1
Volume	(Jan.-Apr. 1986)	(Apr. 1987)	(Sep. 1986)

\* All volumes are in units of acre-feet measured at the beginning of the month.

#### Lake Water Quality

Water samples were collected by Morrison-Knudsen Engineers in 1987 from Lower Derby Lakes, Lakes Mary, and Ladora. In situ water quality measurements and analysis of general water quality indicators, major anions and cations, and primary nutrients were conducted. The in situ measurements included temperature, dissolved oxygen (mg/l and % saturated), pH, conductivity, and transparency (secchi depth). The general water quality indicators included alkalinity, acidity, hardness, total dissolved solids, total suspended solids, turbidity, and true color. The major anions and cations were bicarbonate, carbonate, chloride, sulfate, sodium, potassium, and magnesium. The primary nutrients included nitrate-nitrate N, ammonia N, total Kjeldahl N, organic N, total combined N, dissolved reactive P, and total P. The results of these measurements and analysis are presented in Tables SSA 1.5-1 through SSA 1.5-4.

These data are important for determining the mobility of contaminants in the surface water and will be discussed in Section 3.0.

### Flood Potential

Flood potential within the Irondale Gulch drainage basin was investigated in 1983 by the Army Corps of Engineers (COE, 1983/RIC 84066R01) (Figure SSA 1.5-2). It is reported that in a 100-year flood, dams would be breached at Upper Derby Lake, Lower Derby Lake, and the southernmost Havana Pond (also called South Gate Lake by the Corps). In addition, during a Standard Project Flood (SPF) (a flood of greater than 100-year intensity), the dam at Lake Ladora would be breached (COE, 1983/RIC 84066R01). The Corps stated that "the effects of a series of dam failures on the Rocky Mountain Arsenal would result in very high discharges with a large volume of water." The Corps also determined that the current reservoir system would need to be expanded in order to effectively handle the estimated 60 percent increase in flood water volume likely to occur in the 100-year flood because of increased urbanization to the south.

### Water Balance

Volume II of the Water Remedial Investigation Report, contains a detailed discussion concerning water balances completed for RMA. Excerpts from this volume pertaining to the SSA are presented in the following paragraphs.

Water balance calculations indicate that Upper and Lower Derby Lakes have unaccountable losses of water for 25 of the 26 months monitored. Since all losses except for loss to the groundwater are fairly well accounted for, it appears that these lakes recharge to the water table. Further support of this concept will be provided in the discussion of surface water/groundwater interactions in Section 1.5.5. Aside from loss to the groundwater and evaporation, water may exit Lower Derby Lake through an outlet structure located in the embankment.

Water that is released from Lower Derby Lake passes the Ladora Weir gaging station, enters Sand Creek Lateral, and is diverted into Lake Ladora a short distance away. Water released from Havana Pond may also enter Sand Creek Lateral, but this has only occurred twice over the monitoring period (December 1987 to June 1988). It is not known if the water released from Havana Pond was lost to canal seepage prior to reaching Lake Ladora.

Because releases from Lower Derby Lake to Lake Ladora are manually operated, they are relatively constant with peak flows ranging from 6 to 16 cubic feet per second (cfs). Releases generally occur from July through October when the net evaporation, or evaporation less precipitation, tends to be greatest, and lake levels are lowest.

Sand Creek Lateral diversions provide the only channelized inflow into Ladora Lake. Other sources of inflow include groundwater, direct precipitation, and overland flow. Because Ladora Lake levels are generally greater than 20 ft below those of Lower Derby Lake, it has much greater interaction with the water table. Indeed, water balance calculations indicate that Lake Ladora frequently demonstrates unaccountable net gains. These would primarily be attributable to overland flow or groundwater inflows. Due to the limited areal extent of the watershed, this is a preliminary indicator that groundwater is contributing to Lake Ladora.

Water exits Lake Ladora as seepage, evaporation, overflow, or it may be pumped out via Ladora Pumphouse. Overflows occurred within the monitoring period from December through May. Water that overflows from Lake Ladora travels around Lake Mary into the eastern side of Section 3, where it is lost to evaporation and infiltration. Lake Ladora typically overflows for several months in the winter and spring.

The final lake in the chain is Lake Mary. A drainage culvert at the northwest corner of the lake is the only inlet and it rarely contributes flow. The only three remaining sources of water gain to Lake Mary are direct precipitation, overland flow, or groundwater. Because evaporation generally exceeds precipitation in this area, groundwater appears to be the primary source of water to Lake Mary.

From December 1985 to June 1986, flow was observed in the overflow spillway, located at the south end of Lake Mary. Water table contours indicate that the groundwater flows from east to west. The west end of Lake Mary is above the surrounding water table, and the eastern end below. This suggests that Lake Ladora seepage is the likely source of groundwater feeding Lake Mary.

Any overflow from Lake Ladora flows around Lake Mary to the south, then north along "C" Street. Overflow from Lake Mary contributes to the overflow channel at the south end of Lake Mary. From this confluence, the overflow channel continues a short distance north, passes through a culvert under "C" Street, and finally reaches a small impoundment area to the west. Water has not been observed to pass this final embankment except once when Lake Ladora was deliberately overflowed to test the pathway.

The only significant hydrologic feature remaining in the Irondale Gulch drainage is Havana Ponds. Havana Ponds contain an outlet that may be opened to release water into Sand Creek Lateral. Recorder chart records indicate that this has only been used twice over the monitoring period (December 1987 to June 1988). Havana Pond is rather small, having a maximum capacity of just over 285 acre-feet. The pond is above the water table, and is located in sandy soils. The loss rate from the impoundment is quite large.

Water enters Havana Pond through the Peoria Interceptor channel, which is in turn fed by the Havana Interceptor channel. Although the Peoria Interceptor is the lower order channel, it only contributes 10 percent of the combined flow. Flows into Havana Pond closely reflect precipitation events. This is due to the relatively impervious nature and the small size of the source watershed.

#### **First Creek Drainage Basin**

Essentially all of the SSA is within the Irondale Gulch drainage basin. However, an overflow ditch on the northwest bank of Eastern Upper Derby Lake carries surface run-off to the First Creek drainage basin. The overflow drainage is outside the SSA, and is usually dry. The ditch was designed to carry waters away from Eastern Upper Derby Lake during flood conditions.

The First Creek drainage originates in Arapahoe County, about 15 miles southeast of RMA. The basin is long and narrow, having a length of approximately 17 miles and a maximum width of 4 miles (COE, 1983/RIC 84066R01). First Creek enters RMA at Section 8, flows through the eastern third, and exits RMA from Section 24; it then terminates at its intersection

with O'Brian Canal, about one-half mile north of RMA. First Creek drains about 27 square miles upstream of RMA and 12 square miles within RMA for a total area drained of 39 square miles (COE, 1983/RIC 84066R01). Its average gradient inside RMA is 26 ft/mile, and 31 ft/mile outside RMA. Although poorly channelized outside of RMA, it follows a well defined channel through RMA (Resource Consultants, 1982/RIC 82096R01). Channel straightening was performed on the RMA portion of First Creek after the 1973 flood (COE, 1983/RIC 84066R01). The average run-off into the First Creek drainage system for the period 1971-1979 has been estimated at 687 acre-feet per year (Resource Consultants, 1982/RIC 82096R01).

#### 1.5.2 Vadose (Unsaturated) Zone

The vadose, or unsaturated zone, of the SSA consists mainly of the Bresser/Truckton and Bresser/Satanta soil associations and underlying alluvium. These soil associations are comprised mainly of moderate to coarse textured materials derived from weathered alluvium and eolian deposits, and occur on uplands that are moderate to well drained. The vadose zone ranges in thickness from about 1 ft in the northeastern corner of Section 1 (near the limits of the South Plants groundwater mound) to approximately 37 ft in the southwestern corner of Section 2 (on a topographic high). Apparent factors controlling thickness of the unsaturated zone are surface topography, groundwater mounding under South Plants, and the lakes.

Infiltration rates for the unsaturated zone are estimated from the properties of the soils mapped across the area (Figure SSA 1.4-2 and Table SSA 1.4-1). Infiltration rates are influenced by vegetative patterns, slope and aspect, and moisture content of the soil. On-site measurements of infiltration conditions are presently unavailable. However, qualitative estimates, based on soil texture and structure, have been developed (USDA, 1974/RIC 81266R54; J.P. Walsh & Associates, Inc., 1988). In general, these rates are slow (0.06 to 0.2 inches/hour) to rapid (2.0 to 20.0 inches/hour).

#### 1.5.3 Groundwater

The groundwater systems in the SSA are better characterized north of the lakes than they are south of the lakes. North of the lakes, near South Plants, more wells have been installed and more data have been collected because of the



concern that contaminants may be entering the groundwater in this area (Figure SSA 1.5-3). Fewer wells are present south of the lakes and no RMA facilities are present upgradient of this area.

The following discussion of water bearing zones in the SSA is based on logs of wells installed by various groups and water level data collected by Ebasco in the spring of 1988. Maps presented here may differ in detail from those of the Water Remedial Investigation Report because the data were collected at different time periods, and more site-specific data were collected in the SSA for this report. However, general trends in groundwater flow directions are the same in both reports.

Throughout most of the SSA, five water bearing zones have been identified from close examination of well logs and water level data. The zones identified in the SSA include one in the alluvium (Water Bearing Zone 1A) and four in the Denver Formation (Water Bearing Zones 1, 2, 3, and 4). Distinction of specific water bearing zones in the SSA is mainly based on material properties and saturation. These distinctions have not been confirmed by pump tests.

#### Water Bearing Zone 1A-1

The geologic materials of the alluvium and upper Denver Formation strata comprise an unconfined aquifer with a continuous flow system across RMA; albeit with highly variable hydraulic characteristics.

The uppermost water bearing zone in the SSA is defined as the first zone of saturation below ground surface. In the SSA, this zone is an unconfined aquifer located primarily in the alluvium, but also present in the bedrock in those areas containing unsaturated alluvium (Figure SSA 1.5-5). This zone is designated Water Bearing Zone 1A-1 (WBZ 1A-1). WBZ 1A is located in alluvium while WBZ 1 is located in bedrock. As alluvium thickens to the south, east, and west of South Plants, the nature of the uppermost aquifer changes from saturation principally in the fractured Denver Formation (Zone 1 of South Plants) to saturation in the alluvium (WBZ 1A of the SSA).

WBZ 1A (the alluvial aquifer) is composed mainly of unconsolidated silty sands with lesser clays and gravels (See Section 1.4). Mappable clay units found in the SSA may create minor perched zones or small zones where the aquifer can be confined, but in general, the alluvial aquifer is considered unconfined. Saturated alluvial thickness ranges from 0 to over 70 ft (Figure SSA 1.5-6). The thicker deposits are in areas where alluvium has filled pre-existing channels (paleochannels) in the bedrock surface. As discussed in the following text, these channels may provide preferential groundwater transport pathways in the alluvium. Strata of the Denver Formation included in WBZ 1 consist of weathered claystone, sandstone, and volcaniclastic deposits are described in Section 1.4.

The bottom of WBZ 1A-1 is defined as the greatest depth to which wells can be installed and still have the groundwater rise to the level coincident with the top of WBZ 1A-1. The total thickness of WBZ 1A-1 includes the saturated thickness of alluvial deposits and permeable strata within the Denver Formation.

Examination of well logs, geology and hydrology indicates correlation between Zone 1 of South Plants and WBZ 1 of the SSA (both are saturated zones in the upper portion of the Denver Formation). For the purposes of this discussion, WBZ 1A-1 will be considered one continuous water bearing zone. WBZ 1A-1 is the same as the "Unconfined Flow System" in the Water RI.

WBZ 1A-1 also includes the thickness of less permeable strata within the Denver Formation that contain groundwater in fractures that have potentiometric heads similar to those in overlying unfractured strata.

The top of WBZ 1A-1 is between approximately 0 and 30 feet below ground surface in the SSA. The bottom of WBZ 1A-1 is not as easily defined. As described previously, the uppermost Denver is fractured in many places. The fracturing produces secondary permeability in strata that have a low primary permeability. The base of WBZ 1A-1 is therefore defined by a combination of low permeability claystones or volcaniclastic sediments and lower fracture densities and widths within these strata.

Many of the wells screened in WBZ 1 north of the lakes, are screened in the upper Denver claystones, siltstones, volcanoclastic, and lignite. In the area north of the Derby Lakes, the bottom of WBZ 1 is marked by a traceable lignite approximately 45 to 80 feet in depth.

Water levels have been monitored in some WBZ 1 wells since the early 1980s. These data indicate that water levels have dropped in WBZ 1 nearly 8 feet between 1981 and 1988 (SSA Figure 1.5-8).

Hydrographs for Wells 02008, 02020, 02026, 02001, 02023, and 02034 were analyzed for seasonal fluctuations and were found to range from 1 to 3 ft. The water levels in wells upgradient to Lake Ladora tended steadily to increase from September and peak in June. The seasonal lows occurs in mid-August. Similiar seasonal fluctuations were also noted in Lake Ladora and Lake Mary because both interact directly with the water table (Water RI).

Depth to groundwater in WBZ 1A-1 is an important consideration for evaluating the potential for movement of contaminants from surface sources to the groundwater. Depth to groundwater in the SSA ranges from 0 (at the lakes) to 30 ft (Figure SSA 1.5-9).

Factors believed to influence the direction and rate of groundwater flow in the water table aquifer are the saturated thickness and hydraulic conductivity of the alluvium and Denver Formation; the presence of the South Plants groundwater mound; the lakes system (see Section 1.5.5); and, during times of intense precipitation, the numerous ditches that direct storm water across the area (potentially recharging the groundwater). In general, the water table slope follows the surface topography slope and both dip to the northwest. The highest groundwater elevations recorded are in the southeast portion of the SSA (5,286.90 ft msl); the lowest groundwater elevations are recorded in the northwestern corner of the area (5,174.24 ft msl), for an average gradient of 39.4 ft/mile (0.007 ft/ft). This gradient changes abruptly in the lakes area, where it flattens out to approximately 11 ft/mile (0.002 ft/ft) and in the South Plants area where the groundwater mound causes changes in both gradient and direction of flow (Figure SSA 1.5-5).

Bedrock topography appears to provide some control on groundwater flow direction and rate in the alluvial aquifer, especially where paleochannels have been identified in bedrock. The Irondale paleochannel (filled with alluvial gravel, sand, silt, and clay) trends east-west beneath the area south of the lakes (see Section 1.4). Reported hydraulic conductivities differ significantly between material in the paleochannel and eolian deposits elsewhere in the area, 1060 gpd/ft<sup>2</sup> and 424 gpd/ft<sup>2</sup>, respectively.

Understanding the hydrogeology of the paleochannel is also important to the evaluation of potential contaminant distribution and assessment. The sandy aquifer(s) of the Denver Formation have been truncated by the paleochannel creating subcrops in contact with the alluvium in the channel (Figure SSA 1.4-6). Alluvial groundwater may be in hydrologic communication with aquifers in the Denver Foundation (see Section 1.5.4).

The South Plants groundwater mound plays a major role in directing groundwater flow within the uppermost aquifer through the SSA (May et al., 1983/RIC 83299R01). The mound serves as a groundwater divide, resulting in groundwater flow directions contrary to the regional northwesterly flow. Due to the groundwater mound, in the northern portion of the SSA groundwater flows eastward around the eastern edge of the mound and westward around the southern edge of the mound (Figure SSA 1.5-5).

Little information is available regarding the effects of drainage ditches on groundwater recharge. Soils of the SSA have slow to rapid infiltration rates, moderate to rapid infiltration enhances the probability of groundwater recharge from the ditches during periods of high precipitation.

#### 1.5.3.2 Denver Aquifers

Three additional water bearing zones, or aquifers, have been delineated in the Denver Formation in the SSA (WBZ 2, 3, and 4). These are generally composed of lens-shaped silty sand deposits and typically do not have a high degree of lateral continuity. WBZ 2, 3, and 4 are best defined in the northern portion of the SSA, around the lakes, where Lignite 1A forms a marker bed. Further South in the SSA, fewer wells exist and correlations are not as easy.

Therefore, direct correlation of units between study areas is difficult at best. However, from examination of data, including numerous well logs, head differences between water levels in monitoring wells, and lithologic descriptions, correlation with aquifers in the South Plants Area is possible. Aquifers identified in the SSA (WBZ 2 and 3) appear to correlate with WBZs 2 and 3, described in the South Plants Area Report.

There are very probably more water bearing zones within lower portions of the Denver than the four discussed here. However, this discussion of hydrology addresses those features or water bearing zones most relevant to contaminant distribution and assessment with the available data.

#### Water Bearing Zone 2

Water Bearing Zone 2 (WBZ 2) is the second aquifer identified below ground surface in the SSA. It was delineated in the SSA from potentiometric head differences from WBZ 1A, 1, and 3, and geologic correlation. The potentiometric surface of WBZ 2 indicates general groundwater flow to the west-southwest (Figure SSA 1.5-10). WBZ 2 is located within channel sands (A channel Sands) of the Denver Formation above the LA lignite unit. These units are fine to coarse grained, with minor interbeds of clayey to sandy siltstone and thinly bedded massive claystone.

In the lakes area, WBZ 2 is overlain by approximately 30 to 70 feet of alluvium, claystones, siltstones, volcanoclastics, thin sandstones, and lignites. WBZ 2 is approximately 5 to 50 feet thick. WBZ 2 is underlain by 10 to 50 feet of claystone.

The potentiometric surface of WBZ 2 generally appears distinct from the alluvial aquifer (WBZ 1A) and the uppermost aquifer in the Denver (WBZ 1). North of the western end of Lower Derby Lake there may be areas where WBZ 2 is unconfined. This may be due to fractured portions of the Denver Formation claystone providing hydraulic connection between aquifers, at least locally. These areas could allow contaminant transport between aquifers.

Water levels measured in Wells 01025 indicate that the potentiometric surface of WBZ 2 has risen about 1 foot in this area between 1981 and 1988 (Figure SSA 1.5-11).

#### Water Bearing Zone 3

Water Bearing Zone 3 (WBZ 3) is the third water bearing unit below ground surface delineated in the SSA. Water levels vary from 5,204 ft in Well 02009 to 5,260 ft in Well 02031 (Figure SSA 1.5-12) (Figure 1.5-13). Direction of groundwater flow is generally westward, in agreement with regional flow directions. WBZ 3 is generally comprised of and overlying and underlying sand units the LA lignite unit of the Denver Formation as described in Section 1.4. Within the SSA, WBZ 3 is generally confined and there is significant difference in water levels between WBZ 2 and WBZ 3 as well as between WBZ 1A-1 and WBZ 3.

Water levels measure in Well 01023 indicate that the potentiometric surface in WBZ 3 has remained the same in this area, occasionally dropping a foot in elevation (Figure SSA 1.5-13).

#### Water Bearing Zone 4

Water Bearing Zone 4 (WBZ 4) is the fourth water bearing unit in the SSA. WBZ 4 is comprised of a massive sandstone 10 to 50 feet in thickness. 30 to 50 feet of interbedded claystone and sandstone separate WBZ 4 from Lignite 1A. There are four widely spaced wells screened within WBZ 4 in the SSA; therefore, a figure depicting potentiometric head is not presented. It appears from the available data that WBZ 4 is confined throughout the study area.

In the spring of 1988, the water level elevation in Well 01046 was 5199.61 ft MSL; in Well 01048, 5199.81 ft; in Well 02010, 5167.67 ft; and in Well 02013, 5183.82 ft. This data indicates that the direction of groundwater flow in WBZ 4 is to the northwest. Water levels measured in Well 01046 indicate that the potentiometric surface rose approximately 2 feet between 1981 and 1985; then remained the same (Figure SSA 1.5-14).

#### 1.5.4 Alluvial/Denver Aquifer Interaction

As described in the previous section, there is the potential for Denver Formation Water Bearing Zones to be in contact with the Alluvial-Denver unconfined WBZ 1A-1. The potential for interaction between these water bearing units is evaluated here using water level data collected in April 1988. Only the potential for interaction is discussed because head differences alone would be inconclusive evidence that such interaction is occurring. This discussion also assumes that the wells used for water level measurements were completed properly and isolate the monitored zone from other water bearing zones. However, despite these uncertainties, understanding the potential for groundwater interaction between the various water bearing zones is important for evaluating contaminant pathways in Section 3 of this report.

The difference in head between the unconfined WBZ 1A-1 and the Denver WBZ 2 is shown on Figure SSA 1.5-15. A positive value for the head difference indicates that potential exists for groundwater to move from WBZ 1A-1 to WBZ 2 if they are hydrologically connected. A negative value for the head difference means the converse and indicates that WBA 2 is certainly confined or semiconfined. As Figure SSA 1.5-15 indicates, the head difference is greatest in the northeast section of the SSA, north of Upper Derby Lake, and lowest in the northwest-west side of the SSA around Lake Ladora. These data indicate that there is a potential for groundwater to move downward from WBZ 1A-1 to WBZ 2 in the northeast near the South Plants area and upward in the west-northwest where Zone A sandstones of the Denver Formation subcrop. These data also indicate that groundwater could potentially move from WBZ 2 into WBZ 1A-1 around Lake Ladora where subcropping Denver sands have been mapped (see Section 1.4). The Denver Sands subcrop along the west side of South Plants and south around Lake Ladora. Head differences in these areas indicate that flow may be occurring from the Denver sandstones into the alluvium on the southwest side of South Plants and from the Denver into the alluvium along the remainder of the subcrop.

The head differences between Denver WBZ 2 and 3 were also evaluated for comparison to WBZ 1A-1/2 head differences (Figure SSA 1.5-16). This comparison demonstrates that the potential for groundwater movement is downward from WBZ 2 to WBZ 3.

### Aquifer Characteristics

The Water Remedial Investigation Report (Ebasco, 1989c/RIC 89067R08) identifies seven hydrogeologic units in WBZ 1A-1 (Unconfined Flow System) on the basis of lithologic descriptions and aquifer test results. Six of the hydrogeologic units are located within unconsolidated Quaternary deposits, of which three are found in the SSA and described in Section 1.4. These units form WBZ 1A. Unconfined parts of the Denver Formation are grouped as the seventh or WBZ 1. Aquifer test results, from outside of the SSA, were used to estimate typical values of hydraulic conductivity for each hydrogeologic unit. Table SSA 1.5-5 lists hydraulic conductivities and calculated flow velocities for the hydrogeologic units present in the SSA. The hydraulic conductivities listed for the Paleochannel and Eolian deposits are average values for these units. The hydraulic conductivity for Denver Formation claystone (WBZ 1) is the upper value of the range presented in the water Remedial Investigation Report. This value was used to account for the higher hydraulic conductivity of this formation due to secondary permeability.

The hydraulic conductivity for WBZ 2 is from a slug test conducted on Well 01015, in the SSA. The hydraulic conductivity value for WBZ 3 is an average value from pump tests conducted on deeper Denver sandstones on RMA.

The porosities are average values for the types of materials. A porosity of 40 percent was given to the paleochannel sediments to account for the presence of gravel. Thirty percent is an average porosity for unconsolidated sands and poorly cemented sandstones. A porosity value of 20 percent was given to the Denver Formation claystone to account for weathering and potential fracturing.

The hydraulic gradients were measured from the water table and potentiometric surface maps for the water bearing zones. The hydraulic gradient for the Paleochannel was measured in the area mapped as paleochannel, immediately south of the lakes. The gradient for the eolian deposits and Denver Formation sandstones were measured in the northwest corner of the SSA, north and west of Lake Ladora, where there is well control. The hydraulic gradient for the Denver Formation claystone was measured north of the lakes where the water table is within this formation.



For these estimated values, flow velocities were calculated utilizing Darcy's Law and the continuity equation (Driscoll, 1986). The estimated flow velocities range from 0.04 to 3.02 ft/day in WBZ 1A-1. The estimated flow velocity for water in WBZ 3 is slowest in the Denver Formation sandstones northwest of the lakes and most rapid in the eolian deposits north of Lake Ladora. The flow velocity of groundwater in WBZ 1 is estimated to be 0.17 ft/day north of the lakes. The flow velocity of groundwater in WBZ 2 is estimated to be 1.16 ft/day north of the lakes.

These flow velocities are estimated values based on estimated hydraulic conductivities and porosities. These are not quantified numbers and are only presented here to estimate flow velocities. The actual flow velocities may be several orders of magnitude lower or higher.

#### Recharge/Discharge

Recharge to WBZ 1A-1 occurs as infiltration of precipitation and irrigation, seepage from lakes, canals, ditches, and buried pipelines. Water also enters WBZ 1A-1 by underflow of groundwater from areas north, south and east of the SSA. Water in the transmissive strata of the Denver aquifer flows laterally into the WBZ 1A-1 where the elevation of the bedrock varies appreciably in a short distance and the transmissive strata subcrop. Rates of recharge vary seasonally, have caused relatively minor changes in water levels and flow paths, and will not be discussed in detail.

Discharge from WBZ 1A-1 occurs as seepage to the lakes in the SSA. Additional discharge occurs by evapotranspiration from the water table in areas such as Upper Derby Lake, when it is dry and the water table is within 5 ft of the land surface. Vertical flow probably occurs through fractures in areas where the subcropping strata are predominantly shale or claystone.

Recharge to the Denver Water Bearing Zones (2, 3, and 4) occurs by vertical leakage from the overlying WBZ 1A-1 in areas where the subcropping bedrock is predominantly shale or claystone. Estimates of vertical hydraulic conductivity are not available for the strata in the SSA. However, a single

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pump test conducted near the North Boundary Containment Sytem estimated a vertical hydraulic conductivity of  $4.1 \times 10^{-4}$  ft/day. Recharge to WBZ 2, WBZ 3, and WBZ 4 also occurs by underflow from areas north, south, and east of the SSA. Discharge from WBZ 2, WBZ 3, and WBZ 4 occurs by lateral flow into WBZ 1A-1 where transmissive strata of the Denver aquifer subcrop and the elevation of the bedrock varies appreciably over a short distance. Discharge from these water bearing zones also may occur by leakage to lower Denver aquifers.

A thorough discussion of recharge/discharge of all the water bearing zones on RMA can be found in the Water Remedial Investigation Report.

#### 1.5.5 Surface Water/Groundwater Interaction

An understanding of any interaction between water media is important to the interpretation of distribution, transport, and fate of potential contaminants. Well and lake level data, geologic interpretation, and knowledge of surface and groundwater flow in the area provide enough information for some assumptions or conclusions regarding the relationship between surface water and groundwater.

Composition of the lake bottom materials generally consist of sand and silt. Upper and Lower Derby Lakes were lined with clay upon their construction and later dredged (Section 1.3), probably enhancing the permeability of the lake bottoms. It is unknown how much clay was originally deposited in the lakes or how much material was dredged. Surface water bodies addressed in the SSA are (from east to west) Upper Derby Lake, Lower Derby Lake, Lake Ladora, and Lake Mary. Although there are other surface water bodies in the area (Havana Ponds and Rod and Gun Club Pond), the chain of lakes has been more closely investigated because they are downgradient of any contaminant run-off from South Plants and data are available to attempt a characterization of the surface water and groundwater relationship.

The chain of lakes is essentially a "cascading" system from east to west in the Irondale Gulch drainage basin (Section 1.2). Except for Lake Mary (which

does not have a defined inlet) water flows from lake to lake by a combination of overland flow, culverts, and ditches (ESE, 1988a/RIC 88173R06). A complete discussion of RMA control of surface water flow within the lakes system is provided in the Water Remedial Investigation Report (Ebasco, 1989/RIC 89067R08).

#### **Upper Derby Lake**

According to data collected from October 1985 to May 1986, water balance calculations, and subsequent interpretations by ESE (1988a/RIC 88173R06), Upper Derby Lake (when dry) generally acts as a groundwater discharge area through evapotranspiration. During periods when the lake contains water, groundwater is recharged by the lake (ESE, 1988a/RIC 88173R06). Because there is a lack of downgradient wells, it is difficult to completely assess the relationship between the lake and water table. However, examination of hydrographs from Wells 01021, 01069, and 01070 and water levels for Upper Derby Lake for the period December 1987 to June 1988 reveals a general correlation between the lake levels and levels in nearby wells, thereby supporting the conclusions drawn by ESE (Figure SSA 1.5-17).

#### **Lower Derby Lake**

Groundwater flows south in this vicinity due to the effects of the groundwater mound in the South Plants Area (Figure SSA 1.5-6). The flow direction changes to west after water intersects the Irondale paleochannel south of the lakes. Water balance calculations performed by ESE demonstrate a correlation between lake level and water loss; and the net loss of water in Lower Derby Lake indicates that the lake serves as an aquifer recharge area (ESE, 1988a/RIC 88173R06). Hydrographs of Lower Derby Lake and nearby wells also exhibit correlation between lake levels and well levels (Figure SSA 1.5-18).

#### **Lake Ladora and Lake Mary**

Water balance calculations performed by ESE (1988a/RIC 88173R06) indicate that Lakes Ladora and Mary had a net gain of water for the period December 1987 to June 1988. Such a net gain reflects that the lakes served as an area of groundwater discharge. It should be noted that ESE calculations do not take into account overflow events at these lakes during high precipitation events

(such as in May 1988). Also, the water balance for Lake Ladora is somewhat further complicated from loss of water through seepage into the west bank. However, considering these influences (bank seepage and overflow events), the net effect is still the same for Lake Ladora and Lake Mary: groundwater discharge into the lakes exceeds water loss. Hydrographs from nearby wells and lake levels at Lake Ladora (Figure SSA 1.5-19) indicate water levels in upgradient wells are higher than the level of Lake Ladora. This implies that groundwater may discharge into Lake Ladora.

Hydrographs for Lake Mary and nearby wells do not support or deny that a surface water - groundwater interaction does exist (Figure SSA 1.5-20).

The presence of the lakes affect the groundwater moving south from the South Plants mound. Unconfined groundwater from the south does not flow north of the lakes, and unconfined groundwater from the north does not flow south of the lakes. This indicates that these lakes form a hydrologic barrier. Water moves south from the South Plants mound to the lakes, while groundwater south of the lakes moves in a regional northwest direction.

This discussion has thus far concentrated on the potential for communication between the lakes and the alluvial aquifer. There is also a possibility of communication between the surface water system and/or alluvial groundwater and water bearing units within the Denver Formation. For example, cross-section SS1 (Plate SSA 1.4-1) indicates that upper sand units within the Denver Formation may subcrop below Lake Ladora, allowing for possible interaction of water from Lake Ladora with aquifers of the Denver Formation.

#### **Havana Pond**

Mass balance calculations for Havana Pond indicate that virtually all water entering the pond becomes groundwater recharge. Average recharge is estimated to be 108.3 acre-ft/mo (Ebasco, 1989/RIC 89067R08). Water level data are consistent with this estimate.

#### **Rod and Gun Club Pond and Havana Pond**

Water-balance calculations for Havana Pond indicates that virtually all water

that enters the pond infiltrates into the subsurface; primarily into the first water bearing zone (Ebasco, 1989/RIC 89067R08). Conversely, Rod and Gun Club Pond tends to be recharged by groundwater.

## 1.6 BIOTA

This section summarizing the biotic components of the SSA is an overview of information presented in the Biota Remedial Investigation Report (ESE 1989/RIC 89054R01) (Volume IV of this series). Both terrestrial (vegetation and wildlife communities) and aquatic ecosystems were inventoried and characterized in the SSA from 1985-1988.

This overview summarizes the characteristics of the biota in the SSA, identifies the species of interest that were sampled in the SSA or have the potential to migrate to and from the area, and discusses each species' position in the food chain as it relates to potential contaminant migration pathways and bioaccumulation (as detailed in Sections 2.0 and 3.0).

### 1.6.1 Vegetation

The SSA has the greatest diversity of vegetation types on RMA, and is dominated by vegetation community types considered minor in other study areas: native upland communities, cottonwood/willow stands, and wetland/riparian (Figure SSA 1.6-1). Characteristic riparian types include bottomland meadows and cattail marshes. These vegetation types occur because of the abundance of aquatic resources in this area. Native upland types such as native perennial grassland, sand sagebrush shrubland, and yucca stands are especially well developed in the SSA. Vegetation community types of Arsenal-wide importance are also found in abundance in the SSA including early successional weedy forb and cheatgrass communities that often characterize prior disturbance. Plantings of crested wheatgrass and ornamental trees and shrubs occur in the SSA.

Additional information on the vegetation community types across all of RMA is summarized in the Biota Media Report

### 1.6.2 Terrestrial Wildlife

Wildlife abundance at RMA is related primarily to habitat quality and diversity, low levels of human disturbance, and the absence of hunting and livestock grazing. The great diversity of habitats on RMA provide cover, food, and reproductive habitat for many wildlife species, and in combination with the factors listed above, has led to wildlife populations that are greater on RMA than in similar habitats off-site for many species.

Because of the diversity of habitats in the SSA, most of the wildlife species found on RMA are present here. A complete inventory of RMA wildlife species and details on their distribution in all study areas is found in the Biota Media Report. The discussion below will detail the important wildlife species occurring in the SSA.

#### **Small Mammals**

In the SSA, prairie dog colonies are limited to a small area east of Lake Ladora, the picnic areas in Section 11, and in patches along the southern border of RMA. Desert cottontails frequent the areas near prairie dog towns, while black-tailed jackrabbits seem to be most numerous near the South Plants Study Area boundary and in the area of crested wheatgrass and locusts or plum thickets in Section 11. Eastern cottontails may presumably be present within strictly defined riparian communities in the SSA. Other rodents occurring in the SSA include thirteen-lined and spotted ground squirrels, fox squirrels, muskrats, deer mice, plains harvest mice, western harvest mice, northern grasshopper mice, prairie voles, meadow voles, Ord's kangaroo rats, hispid pocket mice, and silky pocket mice. The small mammals are primary consumers (herbivores) in the food chain and are preyed upon by coyotes, badgers, weasels, foxes, and raptors in the SSA.

#### **Deer**

Both mule and white-tailed deer are common on RMA, including the SSA. Total counts for RMA made by the Colorado DOW in December 1986 were 133 mule deer and 22 white-tailed deer. Total ground counts in 1986-87 by MKE produced numbers as high as 207 mule deer and 56 white-tailed deer. Both species are more abundant on RMA than at off-post comparison areas. The SSA is frequently

used by deer, particularly in the wooded and grassy areas between Upper and Lower Derby Lake. Deer are primary consumers (herbivores) in the food chain. The only possible predators for weakened or young deer in the SSA are coyotes, but dead deer may be scavenged by any of the raptors or carnivores.

#### **Carnivores**

Coyotes range across all sections of the SSA, but avoid the guard station at the southern entrance to RMA and the heavily traveled areas near South Plants. Badgers are also common at RMA, and were observed in prairie dog towns of the SSA during ESE night surveys. Red fox, gray fox, and swift fox were also observed in the SSA, as were raccoons, striped skunks, and long-tailed weasels. The night spotting surveys for the endangered black-footed ferret yielded no sightings (ESE, 1987c/RIC 88194R02).

Carnivores are at the third trophic level as secondary consumers. Coyotes will consume insects as well as a variety of living or dead birds, reptiles, and mammals, whereas badgers are more selective, feeding mostly on small animals.

#### **Raptors**

The SSA includes habitat frequently used by raptors on RMA. Seventeen species of raptors were observed on RMA (including the SSA) by biologists from ESE, USFWS, and MKE.

The ferruginous hawk is the most abundant wintering raptor on RMA (ESE, 1988e/RIC 88293R09). Rough-legged hawks, Cooper's hawks, sharp shinned hawks, red-tailed hawks, and golden eagles are also common at RMA during the winter. Wintering owls include long-eared, short-eared, barn, and great horned owls. During the summer, red-tailed hawks, Swainson's hawks, Northern harriers, and American kestrels are the most common breeding hawk species on RMA. Great horned, long-eared, short-eared, and burrowing owls are common breeding owls.

Twenty-one raptor nests were located across RMA in 1987. The locations of the nests in the Southern Study Area are presented in Figure SSA 1.6-2. The SSA contains most of the raptor nests located, with its abundance of large trees relative to the rest of the Arsenal.

Two species of Federal interest, the bald eagle (a Federally endangered species) and the ferruginous hawk (a species studied for listing by the USFWS) are present on RMA and the SSA in large numbers during the winter months. More than 20 bald eagles roosted on RMA during the past two winters. Bald eagles wintering on RMA feed primarily on prairie dogs and rabbits, many of which are stolen from ferruginous hawks. Bald eagle feeding and perching locations in the SSA were observed in the winters of 1986-1988 (Figure SSA 1.6-2). Eagle observations were particularly common around the lower lakes, but there was little evidence of fish in castings studies by ESE (1988d/RIC 88293R09). A complete explanation of the bald eagles study on RMA, is found in the 1986-1988 Bald Eagle Studies report (ESE, 1988e/RIC 88293R09).

Raptors, like carnivores, are at the third trophic level as secondary consumers. Hawks and eagles depend primarily on prairie dogs, rabbits, and carrion in the SSA. Owls typically consume smaller rodents than the hawks, while kestrels subsist on insects and small rodents.

#### **Water Birds, Upland Game Birds, and Songbirds**

Waterfowl are a prominent wildlife feature in the SSA. Predominant species include the Canada goose, mallard, northern pintail, gadwall, American wigeon, blue-winged and green-winged teal, redhead, lesser scaup, and ruddy duck. Other prevalent water birds include American coots, western grebes, and pied-billed grebes. All of these species, except the pintail, wigeon, scaup, and western grebe, nest on-post.

All of the lakes and ponds in the SSA are frequented by waterfowl. Overall, Lake Ladora is the most heavily used permanent water body on the Arsenal, in terms of total numbers of waterfowl present per count. However, numbers per hectare were higher at some of the smaller water bodies such as Havana Ponds and Lake Mary. Upper Derby Lake was empty at the time of Biota RI studies (1985-1988), but at present contains water and is being utilized by waterfowl.

Wading birds observed in the SSA are the great blue heron and black-crowned night heron. Great blue herons do not nest on-post, but feed regularly in the shallows of the Lower Lakes, Havana Pond, and marshy areas along First Creek.



Black-crowned night herons are less frequently observed, but may have nested on RMA. Gulls and shorebirds seen at the Lower Lakes are typical for the region. Pheasants and mourning doves are common upland game birds that were often seen in riparian and tall grass vegetation types throughout the SSA.

#### **Reptiles and Amphibians**

Several species of reptiles and amphibians also occur in the SSA. Species encountered include the bullsnake, western hognose snake, common gartersnake, plains gartersnake, and yellow-bellied racer. Plains rattlesnakes have also been reported by various field personnel near the lakes. Three lizard species have been sighted in the SSA, including the lesser earless lizard, short-horned lizard, and the many lined skink.

Probably the most abundant amphibian in the SSA is the northern chorus frog. This frog species occurs in large numbers in most cattail stands and intermittent wet areas (such as Upper Derby Lake). The northern leopard frog and the bullfrog were also observed regularly in Lake Mary and Lake Ladora. Woodhouses' toads, Great Plains toads, and plains spadefoot toads have also been observed near the Derby Lakes.

#### **1.6.3 Aquatic Ecosystems**

The description of aquatic habitats in the SSA summarizes studies conducted from 1986 to 1988 by MKE and is discussed in the Biota Media Report. Among the data provided in the above documents are water quality, fish sizes, and fish condition index studies for each lake, which are not included here.

#### **Lakes and Ponds**

The following subsections briefly describe the aquatic resources of lakes and ponds in the SSA. Greater detail is provided for Lakes Mary, Ladora, and Lower Derby because they were the only large permanent water bodies on RMA at the time of sampling and thus were investigated more intensively.

#### **Lower Derby Lake**

Phytoplankton densities in Lower Derby Lake were consistently and substantially higher than in Lakes Ladora or Mary. Diversities however, were

lower than in the other lakes. Green algae dominated the community in April, June, and August, but blue-green algae and cryptophytes were dominant in November. The microzooplankton community of Lower Derby Lake comprised 11 taxa of rotifers. Lower Derby Lake encountered the lowest community diversity of all lakes, but the average density was highest. The macrozooplankton community was dominated by cladocerans and copepods. Benthic macroinvertebrates comprise 63 taxa, mostly oligochaetes (naidids, tubificids) and dipterans (chironomids, culicids). These groups burrow into soft substrate, such as typifies Lower Derby, and generally are tolerant of low dissolved oxygen content.

Eight fish species were captured from Lower Derby Lake. The dominant species were largemouth bass, bluegill, common carp, and black bullhead, which together composed 97 percent of the catch. Other species caught were bluntnose and fathead minnows, green sunfish, and northern pike. Abundances of forage fish were notably low in comparison to predator populations, possibly due to drawdown of the lake below shoreline vegetation that particular year (1986-1988). The fish in Lower Derby showed no unusual numbers of external or gill parasites, and no tumors were observed.

#### Lake Ladora

Phytoplankton density in Lake Ladora was very low in the spring of 1987, and even the highest value in August was much lower than in Lower Derby. Cryptophytes, chrysophytes, and diatoms were dominant overall, with green algae best developed in summer. Community diversity was considerably higher for Ladora than the other lakes, with 36 to 48 taxa identified in the four seasonal samples. Microzooplankton diversity was intermediate between Lower Derby and Mary, with five to seven taxa identified per sampling. Community composition was similar to Lower Derby, but average abundance of rotifers was lower. The peak value in Ladora was also lower than the other Lower Lakes. The average abundance of macrozooplankton in Ladora was intermediate between Lower Derby and Mary and was dominated by cladocerans and copepods. Benthic macroinvertebrate taxa identified in Lake Ladora samples equaled the number from Lake Mary and was slightly higher than Lower Derby. Oligochaetes (tubificids) and dipterans (chironomids) were the prevalent groups identified.

Eight fish species were captured in Lake Ladora, although two species, bluegill and largemouth bass, represented over 97 percent of the catch. Yellow perch and northern pike were the most prevalent of the remaining fish. Other species were the common carp, black bullhead, green sunfish, and pumpkinseed. Unlike the fish community of Lower Derby Lake, that of Lake Ladora was characterized by an over-abundance of forage fish, probably due to the dense growths of aquatic macrophytes and more stable shoreline.

#### Lake Mary

Phytoplankton densities in Lake Mary were the lowest of the south lakes in April, June, and August 1987. The April sample from Lake Mary also had the lowest density of phytoplankton of any samples collected during the field studies, as well as the lowest number of taxa. The average number of phytoplankton taxa for the four seasonal samplings was lower in Lake Mary, than in Lake Ladora or Lower Derby Lake. Green algae were dominant in spring and summer, but diatoms and bluegreen algae were dominant in the fall sample. The microzooplankton community in Lake Mary had an intermediate density, although the peak density in autumn was the highest of the lakes. Diversity ranged from eight taxa in November 1987 to 11 taxa in June. Macrozooplankton diversity was high, with 19 taxa identified, and the community was dominated by copepods and cladocerans. Macrozooplankton density was lower than either Ladora or Lower Derby.

A total of 66 benthic macroinvertebrate taxa were identified in Lake Mary samples. Tubificids and chironomids were dominant, but nematodes, amphipods, and gastropods were more prevalent than in the other two lakes. A large assemblage of insect larvae was also observed in Lake Mary, and was possibly related to the well developed stands of submergent and emergent macrophytes.

Five fish species were captured by electrofishing in 1987: common carp, channel catfish, bluegill, black crappie, and largemouth bass. Of these, bluegill and bass contributed over 96 percent of the catch.

### **Upper Derby Lake**

The broad, shallow nature of Upper Derby Lake, the fact that it generally holds water only during the spring, and the presence of rooted vegetation across most of the substrate make it suitable for breeding by certain amphibians. Springtime vocalization surveys documented reproduction in Upper Derby Lake by northern chorus frogs, plains spadefoot toads, Woodhouse's toads, and Great Plains toads. All but the last species were present in large numbers.

### **Rod and Gun Club Pond**

Although an overflow ditch can carry water from Lower Derby Lake, Rod and Gun Club Pond receives run-off primarily from the surrounding terrain and what little additional area is intercepted by the ditch. There is no drainage outlet. Electrofishing and seining in 1987 failed to produce fish, but the pond was documented to support breeding by northern chorus frogs and Woodhouse's toads.

### **Havana Pond**

This small impoundment retains run-off from residential, commercial, and industrial areas south of RMA, and was surveyed in 1987. No fish were captured, but it supported large breeding populations of northern chorus frogs and Woodhouse's toads in spring.

### **Ditches and Canals**

None of the ditches or canals in the SSA (Highline Lateral, Peoria Ditch, Uvalda Interceptor, Sand Creek Lateral, or Havana Interceptor) were sampled during field investigations because they represent extremely limited aquatic habitat due to their highly irregular flows. However, most contain a small amount of water during much of the year, and probably contribute aquatic invertebrates as well as water and sediments to the Lower Lakes. The Highline Lateral may be a route by which fishes enter RMA waters during periods of flow.

## 2.0 CONTAMINANT DISTRIBUTION

This section discusses analytical methodologies and presents the results of chemical analyses performed on soils (including sediments), surface water, and groundwater samples collected from the SSA. During the RI, nontarget analytes were also investigated for soils, sediments and groundwater and their results are presented in this section, as well. In addition, results are presented for those parts of the structures, air, and biota Remedial Investigations (RIs) that fall within the SSA. Each of these media is discussed separately. For designated contamination sites and nonsource areas studied during the RI, much of the soils analytical data was presented on a site-by-site basis in the Phase I Contamination Assessment Reports (CARs) under Tasks 2, 7, 12, and 15. The Phase I RI program generally was developed to screen areas of potential contamination in unsaturated soils, and to identify areas requiring more intensive investigation. Results of the Phase II investigations conducted under Tasks 20 and 22 are presented in data addenda for the corresponding CAR. The Phase II program was developed to collect sufficient information to quantitatively assess the extent of contamination, and to develop more precise boundaries of contamination. In addition, the Phase II RI methodologies were developed to provide sufficient information to support the feasibility studies and evaluate remediation solutions. The CARs utilized for the compilation of this report have been summarized in Table SSA 1.3-1.

The discussion of contaminant distribution for target analytes is organized by compound groups. Potential contaminants have been grouped into volatile halogenated organics (VHOs), volatile hydrocarbons (VHCs), volatile aromatic organics (VAOs), organosulfur compounds mustard-agent related (OSCMs), organosulfur compounds (OSCs), organophosphorous compounds (OPHs), dibromochloropropane (DBCP), semivolatile halogenated organics (SHOs), organochlorine pesticides (OCPs), arsenic, mercury, and ICP metals (cadmium, copper, chromium, lead, and zinc) (see preface for report, "Target List of Chemical Analyte Groups and Analytes" and Appendix SSA-A for a list of compounds in each group). These compound groupings reflect the Phase II analytical methods for related families of compounds as well as similar origins and environmental properties.

Data from other investigations are also discussed in this section, including data from the USAEWES, Geraghty and Miller, Dames and Moore, and Shell Oil Company and its affiliate, Shell Chemical Company (collectively referred to as Shell). This background information is used, in association with the analytical results from the RI program, to assess potential impacts by numerous sources of contamination in the SSA.

Surface water data presented in this section were compiled from the Water RI Report (Ebasco, 1989/RIC 89067R08) and other investigations conducted from 1980 through 1987, including reports by Shell, USAEWES (Myers & Gregg, Spaine & Gregg, 1983/RIC 84086R01), and Dames and Moore.

Groundwater data presented in this section were collected by ESE in 1985, 1986, and 1987 during the RI, and by MKE during the summer of 1988. In the fall of 1985 and most of 1986 (fiscal year 1986), ESE performed a groundwater surveillance program under Task 4. Data were collected during each quarter of this fiscal year, however, not all wells in the SSA were sampled every quarter. In the spring of 1987, under Task 44, more data were collected to further assess the distribution and concentration levels of groundwater contaminants detected under Task 4. These data will be reported in the Water Remedial Investigation. Data were also collected by MKE from wells sampled in Sections 1 and 2 of RMA during the summer of 1988. These wells can be identified on groundwater figures and tables by the number "5" in the third digit of a well number sequence, i.e., Well 02577.

## 2.1 SOIL AND SEDIMENT SAMPLES

Soil and sediment samples were collected from 16 sites and portions of six sections in the SSA. A total of 474 borings, yielding 171 composite and 736 uncomposited soil and sediment samples, were completed in the SSA during Phase I and II remedial investigations under Tasks 2, 7, 12, 15, 20, and 22. Most of the sampling was conducted using hollow-stem auger drilling techniques. A list of all analytes investigated and their respective certified reporting limits (CRL) is presented in Appendix SSA-A, Part I.

### 2.1.1 Sampling Program and Analytical Methods

The soils investigation at RMA was conducted in two phases. Phase I investigations identified potential contaminants and provided a preliminary assessment of the vertical and lateral extent of contaminants. Phase I results also provided the basis for the design of a more quantitative Phase II program. Phase II sampling was conducted at some sites to provide a more quantitative assessment of the vertical and areal extent of detected potential contamination. Data from Phase I of the RI were published in the Contamination Assessment Report for each site, and Phase II data were published in Phase II Data Addenda. These documents are listed and referenced in Section 1.1 of this report.

In the Phase I program, soil borings were drilled to various depths in the vadose zone. Within sites, samples were generally collected from these borings at standard sampling depths of 0 to 1, 4 to 5, 9 to 10, 14 to 15, and 19 to 20 ft. Samples were collected from nonstandard intervals where drilling was difficult or where staining or other evidence of potential contamination was observed in the core. In areas outside sites, samples were normally composites of the 0 to 1 and 4 to 5 ft intervals. Phase II samples were collected either at standard intervals or in depth intervals clustered around Phase I samples that were re-evaluated by the Phase II samples.

Samples from the Phase I borings were analyzed for a standard suite of analyses. The Phase I analyses for target compounds included:

- o gas chromatography/mass spectrometry (GC/MS) analysis for volatile organics (VOs);
- o GC/MS for semivolatile organics (SVOs);  
gas chromatography/electron capture (GC/EC) analysis for DBCP;
- o inductively coupled plasma (ICP) screen for the metals cadmium, chromium, copper, lead, and zinc;
- o atomic absorption spectroscopy (AA) for arsenic; and
- o cold vapor atomic absorption spectroscopy (CVAA) for mercury.

The organic compounds for which the VO and SVO methods were certified are listed in Appendix SSA-A.

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In the SSA sites, the GC/MS analysis for VO's was applied only to samples from below the 0 to 1 ft depth interval, since volatiles could be expected to have evaporated from surface soils. Exceptions occurred in the lakes area, where sampled sediments were submerged. VO's were normally not analyzed in samples collected outside of the SSA sites, as the sample from these other areas were composites of the 0 to 1 and 4 to 5 ft intervals. For other methods applied to these composite samples, under worst-case conditions, compositing effectively doubled the CRLs for these samples.

Where GC/MS methods were used, compounds were tentatively identified by establishing a "best fit" identification using a computer library of spectra. Some of these compounds have been added to the list of target compounds that are evaluated by the SARs. These tentatively identified compounds are:

VHOS

1,1,2,2-Tetrachlorethane  
Trichloropropene

VHCs

2-Butoxyethanol  
4-Hydroxy-4-methyl-2-pentanone  
1-Methyl-1,3-cyclopentadiene  
Methylcyclohexane  
2,2-Oxybisethanol  
2-Pentanone

OPHGBs

Phosphoric acid, tributyl ester  
Phosphoric acid, triphenyl ester

ONCs

Caprolactam

PAHs

Fluoranthene  
Methylnaphthalene  
Phenanthrene  
Pyrene



**SHOs**

Trichlorobenzene  
Hexachlorobenzene  
Hexachlorobutadiene  
Tetrachlorobenzene  
Pentachlorobenzene

Because the method used to identify these compound has not been subjected to U.S. Army Toxic and Hazardous Materials Agency certification procedures, they have no CRL. The lower limit of detection has been assumed to correspond to 10 percent of the internal standard for the GC/MS methods used, which is 0.3 ug/g.

The GC/MS analyses for VOs and SVOs were certified by the US Army Toxic and Hazardous Materials Agency to detect a variety of analytes (listed in Appendix SSA-A) to accomplish the Phase I objective of identifying contaminants present in the study area. Phase II methods were developed and certified for use in further quantifying the concentrations of the target compounds identified in Phase I. These Phase II methods and the analytes detected by each method are also listed in Appendix SSA-A. The Phase II methods were more sensitive GC methods certified for fewer compounds at lower reporting limits. In addition, approximately 10 percent of the samples analyzed by GC methods were also analyzed by GC/MS for confirmation of the GC results. The Phase II methods and the analytes for which these methods were certified are listed in Appendix SSA-A. The CRLs for these methods are shown for each detected analyte in Table SSA 2.1-1.

Six laboratories performed analyses on soils and water samples collected during the RI. The analytic and quality assurance techniques employed during certification of analytical methods in the separate laboratories led to the establishment of lower and upper CRLs that are method, analyte, laboratory, and machine specific. Therefore the reported CRL may vary between samples. Lower CRLs for analytes detected during the RI fall within a range established by the most and least sensitive meethods from among the six laboratories.

This lower CRL range is presented for each analyte in soil samples in Table SSA 2.2-1. Data values falling below their respective CRLs are reported as below CRL (BCRL). The most and least sensitive methods from among the six laboratories also define a range of upper CRLs; however, in some cases it was possible to report a value greater than the upper CRL while maintaining the litigation quality of the data. To accomplish this, samples with higher contaminant concentrations were diluted so that the instrument reading for the diluted sample fell below the CRL, and only exceeded the CRL when the dilution factor was applied to arrive at the final result. Data for these diluted samples represent the only values above the upper CRL that can be reported with the degree of accuracy and precision required by the U.S. Army Toxic and Hazardous Materials Agency.

In cases where the analytical values exceed the upper CRL and the samples were not diluted, an attempt was made to recover the actual instrument readings from the laboratory. This information was used to gain a qualitative understanding of the relative level of contamination in the samples. These results that were above the upper CRL are not of litigation quality and cannot be used with the same confidence as those falling within the CRLs.

To provide a complete review of information pertinent to the contamination assessment at RMA, data from investigations other than the RI have been included in this and previous reports where appropriate, even though the methods used were not U.S. Army Toxic and Hazardous Materials Agency certified. This use has set a precedent to consider nonlitigation quality data along with the litigation quality results obtained under the RI.

The inclusion of nonlitigation quality data was also done in consideration of the fact that sophisticated statistical manipulations of the data would not be carried out for the purposes of the Study Area reports. Such manipulations were deemed inappropriate considering the large numbers of values that fell below the various lower CRLs as well as those values (estimated to be approximately one percent of the data set) that fell above the upper CRLs and were not the result of approved dilution procedures. It was determined that statistical manipulations of more limited data sets, such as those obtained

from a single site, would be more appropriate and accurate for the FS. In the FS phase, more limited statistical evaluations could then be used to evaluate, on a case-by-case basis, the effects of the nonlitigation quality or out-of-range data on the contamination assessment and on the evaluation and selection of appropriate remedial measures.

#### 2.1.2 Analytical Results

A summary list of the compounds detected above the CRLs in SSA soils and sediments is presented by analyte group and sampling site ie. lakes, buried lake sediments, ditches, etc. in Table SSA 2.1-1. These results represent the sample concentrations of each analyte less any concentration detected in the method blanks and are reported in micrograms per gram (ug/g) to one or two significant figures, depending upon the method used.

In order to present the analytical data in a summary form for this report, contaminant distribution maps are constructed by analyte group rather than by individual analyte, and data were grouped together over depth intervals larger than the standard sampling intervals. To further simplify the presentation of the analyte levels, ranges of concentrations are shown by dots of different sizes.

Separate maps were used to represent the results for samples falling in the 0 to 2, 2 to 5, and 5 to 20 ft depth intervals. Because of the relatively large depth intervals chosen for the maps showing analytes in soils, one dot may represent more than one sample from a given soil boring. A single dot may also represent from one to all of the analytes detected in an analyte group at a given location. For these reasons, the number of dots on a map may be less than the number of samples analyzed. Results for composite samples are shown on the maps for both depth intervals.

For the organic compounds, the soils data reported for each boring were separated into the depth intervals used in the maps. Next, the data were separated into analyte groups. To compute the total concentration of each group in the boring, the highest concentration of each analyte in the group was summed. The resulting sum is equal to or greater than the total

concentration of that group in any one sample. This worst-case concentration is and represented on the map by the dot size corresponding to the concentration range attained.

The concentrations for the organic analyte groups were divided into four ranges, and are represented by progressively larger dots. The concentration ranges were based upon the following criteria:

- 1) Lowest CRL to 1.0 ug/g.
- 2) 1.0 ug/g to next order of magnitude.
- 3,4) Subsequent ranges based on orders of magnitude, not to exceed four ranges per map.

ICP metals were also mapped as group since these analytes commonly occurred together. However, since metals concentrations were evaluated with respect to their natural concentrations in RMA soils, they were treated differently than organic analytes.

First, each metal concentration was compared to an indicator range of natural concentrations. During the RI, indicator levels and ranges were established to assess the significant of the analytical values for target analytes in soils. The indicator levels for organic compound are the CRLs of the analytical methods for these compounds. The indicator ranges for metals reflect the concentrations expected to occur naturally in RMA alluvial soils (ESE, 1987/RIC 88204R02). The upper limits of these ranges are:

<u>Metal</u>	<u>Concentration (ug/g)</u>
Arsenic	10
Cadmium	2.0
Chromium	40
Copper	35
Lead	40
Mercury	0.10
Zinc	80

Each ICP metal has a different indicator range and therefore cannot be compared directly on the basis of absolute concentration. For this reason, and because these metals tended to occur together in the WSA, the metals concentrations are not added together to give a total for plotting. Instead,

the metal concentrations were compared to their indicator ranges and assigned to a relative range. The highest range attained by any one ICP metal in a given depth interval is represented on the map. The metal specific concentration ranges are based on the indicator ranges of the metals, as follows:

<u>Metal</u>	<u>Range 1</u>	<u>Range 2</u>	<u>Range 3</u>	<u>Range 4</u>
Cadmium	CRL-2.0	2.0-10	10-100	>100
Chromium	CRL-40	40-100	100-1,000	>1,000
Copper	CRL-35	35-100	100-1,000	>1,000
Lead	CRL-40	40-100	100-1,000	>1,000
Zinc	CRL-80	80-1,000	1,000-10,000	>10,000

Because metals concentrations below the upper limits of the indicator ranges are considered to be consistent with natural conditions, results that do not exceed those indicator ranges are shown on the analyte distribution maps as open circles, like BCRL results. Values above the indicator ranges are shown as solid dots. The significance of the metals concentrations greater than their indicator ranges are discussed further in the contamination assessment section of the report (Section 3.0).

Of the ten target analyte groups presented in Table SSA 2.1-1, analytes identified most frequently are summarily displayed in figures in this report. VHO compounds are displayed in Figures SSA 2.1-1 through SSA 2.1-3. Methylene chloride, a VHO, is separately shown on Figures SSA 2.1-4 through SSA 2.1-6. DBCP is shown in Figures SSA 2.1-7 through SSA 2.1-9. SHO compounds are shown in Figures SSA 2.1-10 through SSA 2.1-12. The OCPs are separated into two subgroups and reported on Figures SSA 2.1-13 through SSA 2.1-18. Arsenic and mercury are reported on Figures SSA 2.1-19 through SSA 2.1-21 and SSA 2.1-22 through SSA 2.1-24, respectively. ICP metals are reported on Figures SSA 2.1-25 through SSA 2.1-27. Together, analytes presented on the figures represent over 97 percent of the total number of samples in which a target analyte was detected in the SSA. VAOs and VHCs represent the remaining two analytical groups detected in samples collected from the SSA. They are discussed in the following section, but are not presented on figures due to the infrequent number of detections of analytes within these two groups.

### 2.1.3 Distribution of Analytes

The following subsections (2.1.3.1 through 2.1.3.9) present the areal and vertical distribution of analytes in soils and sediments, by analyte or analyte group. Figures are not presented for analytical groups where detections in that group are scattered or sparse.

#### 2.1.3.1 Volatile Halogenated Organics

The volatile halogenated organics (VHO) group includes 12 compounds. Within this analytical group, six compounds were detected in the SSA, including carbon tetrachloride, chloroform, methylene chloride, tetrachloroethylene, 1,1,1-trichloroethane, and 1,1,2,2-tetrachloroethane. (Figures SSA 2.1-1 through SSA 2.1-3)

Up to 156 samples were collected in the SSA and analyzed for each of the VHOs. Carbon tetrachloride was detected in two samples, chloroform in one sample, methylene chloride in 12 samples, tetrachloroethylene in one sample, 1,1,1-trichloroethane in two samples, and 1,1,2,2-tetrachloroethane in 12 samples. The concentration ranges for the individual analytes are as follows: carbon tetrachloride 0.39 to 0.73 ug/g; chloroform 0.81 ug/g; methylene chloride at 1.0 to 5.1 ug/g; tetrachloroethylene at 1.0 ug/g; 1,1,1-trichloroethane at 0.37 to 0.6 ug/g; and 1,1,2,2-tetrachloroethane at 0.4 to 2.0 ug/g.

The VHOs were detected predominantly in the ditch and overflow basin in Sections 2 and 3, west of Lake Mary (Sites 3-2/3-3) are shown on Table SSA 2.1-1. 1,1,2,2-Tetrachloroethane was detected on nine occasions at this site. The VHOs were also detected sporadically in Lake Ladora, Upper Derby Lake, and Eastern Upper Derby Lake, as well as the nonsource area of Section 11. The majority of the detections occurred in the 2 to 5 ft depth interval, with fewer occurrences in the 0 to 2 and 5 to 20 ft depth intervals.

Methylene chloride was reported in eight samples from four borings in Lake Ladora, at concentrations ranging from 1.5 to 2.1 ug/g. The analyte was detected in the inlet channel from Lower Derby Lake and the central portion of Lake Ladora. Methylene chloride was also detected in samples from the

overflow basin (Site 3-3) and from the trench (Site 2-5) and open storage areas (Site 2-15) of Section 2, south of Lake Ladora (Figures SSA 2.1-4 through SSA 2.1-6). Methylene chloride was never detected in method blanks.

#### 2.1.3.2 Volatile Hydrocarbons

The volatile hydrocarbons (VHCs) group includes nine compounds. From this group, only dicyclopentadiene and methylisobutyl ketone were detected in the SSA. Dicyclopentadiene was detected once out of 594 analyses, while methylisobutyl ketone was detected once out of 144 analyses. Dicyclopentadiene and methylisobutyl ketone were detected in separate samples at concentrations of 2.5 ug/g and 1.0 ug/g, respectively.

Dicyclopentadiene was detected in the Section 1 trash dump, and methylisobutyl ketone was detected once in the northern portion of Lake Ladora. In both cases, these compounds were detected in 2 to 5 ft intervals and occurred with other significant organic compounds.

#### 2.1.3.3 Volatile Aromatic Organics

The volatile aromatic organics (VAO) group includes five compounds of which only toluene was detected in the SSA. Toluene was detected twice in 153 analyses, at concentrations of 0.4 ug/g. These samples were collected in the Section 1 ditch system, south and east of South Plants and in a nonsource area of Section 11, immediately south of the buried lake sediments. Toluene was detected in the Section 1 ditch in the 2 to 5 ft depth interval. This particular ditch was eliminated from the process waste system in 1963. Toluene was not detected in the buried sediments north of its detection in Section 11.

#### 2.1.3.4 Dibromochloropropane

Dibromochloropropane (DBCP) was detected in samples collected from lake bottom sediments, buried lake sediments, and nonsource areas (Figures SSA 2.1-4 through SSA 2.1-9). A total of 650 samples were analyzed for DBCP using volatile and semivolatile (GC/MS) methods as well as specific GC analyses. DBCP was not detected using GC/MS methods, but was detected in 32 samples analyzed by GC. Detected concentrations ranged from 0.0068 to 0.65 ug/g.

Twenty-eight of the 32 samples in which DBCP was detected (approximately 87 percent) were collected from the lakes. Of these 28 detections, 24 occurred in Lower Derby Lake and four in Lake Ladora. The remaining four samples containing DBCP were isolated, and collected from (Section 12, buried lake sediments) and (in the nonsource areas of Sections 1 and 12).

In the lakes region, DBCP was detected in the surface sediments (0 to 2 ft) of Lower Derby Lake in 18 of 38 samples collected (47 percent). The highest concentrations of DBCP (0.3 ug/g) occurred in the 0 to 2 ft depth interval. The compound was detected in five of 28 samples collected (18 percent) at depths from 2 to 5 ft, and in only one of eight samples collected (12.5 percent) below 5 ft. This contaminant distribution pattern is possibly due to degradation of DBCP in the deeper, older sediments over time; sedimentation of contaminated materials over older, cleaner sediments; or adsorption to organic surfaces in the surface sediments. Additionally, DBCP was distributed most frequently at the mouth of the Section 1 process water ditch, which extends to the lowest portions of Lower Derby Lake. Within Lake Ladora, two detections each were reported in the 0 to 2 and 2 to 5 ft intervals, respectively. There were too few detections to assess a pattern of contamination or a concentration gradient.

#### 2.1.3.5 Semivolatile Halogenated Organics

The semivolatile halogenated organics (SHO) group includes six analytes, of which only hexachlorocyclopentadiene was detected in the SSA (Figures SSA 2.1-10 through SSA 2.1-12). Hexachlorocyclopentadiene was detected in 17 of 741 samples, in concentrations ranging from 0.0061 to 0.35 ug/g. Of the 17 detections, 13 occurred in the 0 to 2 ft depth interval and four occurred in the 2 to 5 ft depth interval. There was no definitive concentration gradient observed between depth intervals. Hexachlorocyclopentadiene was detected predominantly in the surface and subsurface intervals of Upper Derby Lake (Site 1-2), the Section 2 drainage ditches (Site 2-1), the Section 1 trash dump and adjacent nonsource area, and the buried lake sediments in Section 12 (Site 12-1).



Hexachlorocyclopentadiene was frequently detected in the watershed at the higher points into which runoff or process water from South Plants drained. Specifically, it was detected along numerous discharge points in the western portion of South Plants, upgradient of the Sand Creek Lateral segment of the Section 2 ditch system. Concentrations in the western portion of South Plants ranged from below 1.0 ug/g in the ditches of SPSA to over 100 ug/g in SPSA-8A (the sanitary landfill).

#### 2.1.3.6. Organochlorine Pesticides

The organochlorine pesticides (OCP) group includes seven compounds that were all detected in the SSA (Figures SSA 2.1-13 through SSA 2.1-18). The compounds include aldrin, dieldrin, endrin, isodrin, chlordane, dichlorodiphenylethane (DDE), and dichlorodiphenyltrichloroethane (DDT).

For the purposes of discussion and presentation, these compounds have been separated into two groups: Subgroup I includes aldrin, dieldrin, endrin, and isodrin; and, Subgroup II includes DDE, DDT, and chlordane. Historically, both DDT and chlordane were used extensively across RMA, including the SSA, for insect control purposes. DDT was reportedly sprayed near Lake Ladora and along canals and ditches leading throughout the South Lakes area (ESE, 1989). Apparently, Army usage of DDT at RMA continued from the mid-1940s well into the 1960s. Chlordane was also reportedly used to control pests in the 1950s. Although dieldrin was reported to be used for insect control, its use was sporadic and not nearly as widespread as DDT or chlordane. It was not until 1972 that the Army specifically regulated the use and handling of DDT, chlordane, and a variety of other similar pesticides.

Chemically, OCPs from both subgroups behave similarly in soil environments. However, DDT, DDE, and chlordane are unrelated to the Subgroup I compounds both metabolically and from a manufacturing perspective. DDT and DDE are two of the more persistent OCPs (Edwards, 1972). This may be due in part to studies that have shown that DDT can more easily realign its structure into a planar configuration than dieldrin. This greater ease for restructuring to this type of configuration enables DDT to be better adsorbed to soil surfaces (Dragun, 1988).

OCPs from both subgroups were detected in SSA biota. However, there are differences in physiological mechanisms, responses, and concentration doses found to affect biota between compounds in the two subgroups.

Finally, although the distribution patterns between Subgroup I OCPs and Subgroup II OCPs are similar in the SSA, concentration gradients differed slightly within several areas of the SSA. As an example, concentrations of aldrin, dieldrin, and the remaining Subgroup I OCPs were up to 10 times higher in the Sand Creek Lateral than corresponding concentrations of DDT and DDE. Subgroup I OCPs were also found to be more widely distributed in Section 12 buried lake sediments than Subgroup II OCPs. Furthermore, across the entire SSA, nearly two-thirds of the OCP detections were from Subgroup I analytes. This 2:1 frequency ratio as well as the other factors listed above, were important in dividing the OCPs into two subgroups.

OCPs were detected primarily in the ditches and overflow basins south and west of South Plants and from the lakes and buried lake sediments in the SSA. A small percentage of samples taken from the disposal areas and miscellaneous surface disturbance areas also contained OCPs. OCPs were detected in 504 of 823 samples collected from the SSA and analyzed for OCPs. Dieldrin was detected in 144 samples, aldrin in 118 samples, DDE in 67 samples, DDT in 54 samples, endrin in 45 samples, isodrin in 41 samples, and chlordane in 35 samples. The concentration ranges for the analytes, which are shown as cumulative totals in the figures, are as follows: dieldrin 0.0038 to 290 ug/g; aldrin 0.0024 to 400 ug/g; DDE 0.0031 to 5.6 ug/g; DDT 0.003 to 88 ug/g; endrin 0.0069 to 37 ug/g; isodrin 0.0016 to 4.0 ug/g; and chlordane 0.038 to 55 ug/g.

A total of 182, or 36 percent, of the samples in which organochlorine pesticides were detected were taken from the lakes. Aldrin (49 detections), dieldrin (41 detections), isodrin (13 detections), and endrin (12 detections) accounted for 63 percent of the detections from the lakes. DDE (30 detections), DDT (18 detections), and chlordane (19 detections) accounted for 37 percent of the detections. Overall OCP detections were widespread throughout the lakes area, although most detections occurred in Upper and

Lower Derby Lakes and Lake Ladora. In Upper Derby Lake, Subgroup I OCPs were detected twice as frequently in the 0 to 2 ft depth interval (37 detections) than the 2 to 5 ft depth interval (18 detections). Lower Derby Lake depth distributions were similar to observations in Upper Derby Lake. In contrast, detections of Subgroup I OCPs occurred seven times more often in the 0 to 2 ft depth interval of Lake Ladora than in the 2 to 5 ft depth interval. In Eastern Upper Derby Lake, Rod and Gun Club Pond, and Lake Mary, Subgroup I pattern of Subgroup II OCPs was similar to the observed pattern of Subgroup I OCPs. The three Subgroup II compounds had a tendency to occur three times as often in the 0 to 2 ft depth intervals in Upper and Lower Derby Lake as in the OCPs were detected only in the 0 to 2 ft depth intervals. The distribution deeper intervals sampled. Detections of the Subgroup II compounds from Lake Ladora, Lake Mary, and Rod and Gun Club Pond were limited to the 0 to 2 ft depth intervals. None of the Subgroup II compounds were detected in samples from Eastern Upper Derby Lake.

OCPs were detected in 173 samples collected from the drainage ditches and overflow basins. This represented 34 percent of all organochlorine pesticide detections from the SSA. Dieldrin (57 detections), aldrin (37 detections), isodrin (16 detections) and endrin (17 detections) accounted for 73 percent of the compounds detected in this subarea. DDE (21 detections), DDT (18 detections), and chlordane (7 detections) accounted for the remaining 27 percent of the OCP detections.

Greater than 58 percent of the samples collected from the Section 2 drainage ditches, south and west of South Plants, and in portions of the Sand Creek Lateral north of Lake Ladora were reported to contain OCPs. Of the 100 OCP detections occurring in the Section 2 ditches, 75 percent were Subgroup I analytes. Subgroup I analytes tended to accumulate in the 0 to 2 ft depth interval twice as often as in the 2 to 5 ft depth interval, and over four times as often than in the greater than 5 ft depth interval. Subgroup II analytes occurred in the 0 to 2 ft depth interval with three times the frequency as in the 2 to 5 ft depth interval. As shown on Figures SSA 2.1-13 through SSA 2.1-18, concentration gradients for these analytes decreased dramatically with depth. Thirty-three percent of the OCP detections in the

ditches and overflow basins occurred in the Section 1 process water ditch system. Unlike the Section 2 ditch system, the frequency of detection of Subgroup I and II analytes in the Section 1 ditches was evenly distributed between the three intervals. However, like the Section 2 ditches, the highest concentrations of both Subgroup I and II analytes occurred in the 0 to 2 ft depth intervals. Also in this ditch system, contaminants tended to be entrained primarily in the bottoms of the ditches, as opposed to the ditch banks. The remaining nine percent of the OCP detections in occurred in the ditch and overflow basin west of Lake Mary. Most detections occurred within the ditch bottom of the overflow basin to the west of "C" Street. Subgroup II analytes were detected twice as often as Subgroup I analytes. Two-thirds of the OCP detections and the highest concentrations occurred in the 0 to 2 ft depth interval.

Organochlorine pesticides were detected in 93 samples collected from buried lake sediments. This constituted about 19 percent of all samples containing OCPs in the SSA. All of the OCP detections from Section 12 occurred in the buried lake sediments immediately north of Rod and Gun Club Pond. Aldrin (22 detections) and dieldrin (34 detections) accounted for 60 percent of the detections of all OCPs from this area. The remaining Subgroup I compounds, endrin (8 detections), and isodrin (7 detections) accounted for 16 percent of the detections. DDE (10 detections), DDT (9 detections), and chlordane (3 detections) accounted for the remaining 22 detections, or 24 percent. Seventy-six percent of all OCP detections occurred at depths greater than 2 ft, which is consistent with the historical construction specifications of the site (see Section 1.3.2.3). Subgroup I compounds were detected twice as often and at the highest concentrations in subsurface than in surface intervals, while the distribution of Subgroup II compounds was evenly distributed among all depths sampled. Subgroup II compound concentrations were found to increase by as much as two orders of magnitude with depth.

Organochlorine pesticides were detected in 15 samples collected from Section 1, trash dump. This is less than three percent of the total number of samples containing OCPs collected from the entire study area. All OCPs were detected in samples collected from the Section 1 trash dump, north of Lower Derby Lake. Subgroup I analytes constituted over 70 percent of the analytes

detected (11 of 15 detections). The remaining four detections occurred between the three Subgroup II analytes. No single analyte in either of the two subgroups clearly stands out as a predominant contaminant. Thirteen of the 15 detections occurred in the 0 to 2 ft depth interval in this subarea.

Nonsource locations in the SSA, which, based upon historical investigations, were areas not used for the manufacture, storage, or disposal of contaminated materials. Samples collected from numerous boring locations scattered throughout Section 1 north of Lower Derby Lake, and particularly east-northeast of the Section 1 trash dump contained OCPs. In Section 1, OCPs were detected in 40 samples, of which dieldrin was the most common (8 detections), followed by aldrin and DDT (7 detections each). Although there was no discernible difference in the frequency of detection of OCPs with depth, there was a noticeable decrease in concentration range with depth in the Section 1 nonsource area. All OCPs were detected at least four times in the nonsource areas. One isolated occurrence of chlordane (4.0 ug/g) was detected in Section 11. Total OCP detections in nonsource areas constituted eight percent of all SSA detections.

In summary, OCPs were detected in the SSA mainly within the top 2 ft of soil and in lake bottom sediments. Samples obtained from the 0 to 2 ft depth interval contained 47 to 69 percent of all detections in the subareas of each of the OCPs. Samples from the 2 to 5 ft depth intervals contained from 28 to 35 percent of the individual OCP detections, and samples from intervals deeper than 5 ft contained 3 to 18 percent of the individual OCP detections. Subgroup II compounds were detected 20 percent more often than Subgroup I compounds in the 0 to 2 ft depth interval. Subgroup I compounds were detected over three times as often as Subgroup II compounds at depths exceeding 5 ft.

#### 2.1.3.7 Arsenic

Arsenic was detected in 32 of 451 samples analyzed for arsenic from the SSA (Figures SSA 2.1-19 through SSA 2.1-21). The highest concentrations of arsenic were found in the surface sediments of Upper Derby Lake and Lake Ladora. It was detected at concentrations within its indicator range in 87 percent of the samples in which it was detected. Arsenic was detected

above its indicator range in 12 percent of the samples in which it was detected. The following summary table shows the frequency at which concentrations of arsenic exceeded the upper limit of its indicator range relative to the total number of samples in which it was detected.

Percent Frequency of Detections Above Upper Limit Indicator Level (IL).

<u>Concentration (ppm)</u>	<u>0 to 2 ft</u>	<u>2 to 5 ft</u>
0-10 (IL)	50	38
10-100	12	0

Concentrations of arsenic in the SSA ranged from 2.9 to 16 ug/g. Twenty-three of the 32 detections (72 percent) occurred in samples from the lakes, primarily in Upper Derby Lake and Lake Ladora (10 detections each). The highest frequency of arsenic concentrations occurred in surface sediments. Gradual reductions in frequency and concentration occurred with increased depth. Arsenic was also detected in a few locations in Lake Mary and Eastern Upper Derby Lake.

Arsenic was detected in eight samples, four of which occurred in the ditch and overflow basin west of Lake Mary. Concentrations were also the highest at this location. Arsenic was detected sporadically at low concentrations in the Sections 1 and 2 ditch systems.

Arsenic was detected only once (at 3.0 ug/g) in the buried lake sediments in Section 12.

#### 2.1.3.8 Mercury

Mercury was detected in samples collected from the lakes, primarily Upper and Lower Derby Lakes, and from the ditches and overflow basin in concentrations ranging from 0.053 to 18 ug/g (Figures SSA 2.1-22 through SSA 2.1-24). Of the 683 samples analyzed, 142 samples or 21 percent, contained detectable levels of mercury. Ninety-three samples had mercury concentrations above its indicator range. The following table summarizes the frequency at which mercury concentrations exceeded the upper limit of its indicator range with respect to the total number of samples in which mercury was detected.

Percent Frequency of Detections Above Upper Limit Indicator Level (IL)

<u>Concentration (ppm)</u>	<u>0 to 2 ft</u>	<u>2 to 5 ft</u>	<u>greater than 5 ft</u>
0 - 0.1 (IL)	21	11	2
greater than 1.0	42	16	8

In the lakes area, mercury was detected in 68 samples, constituting 48 percent of all mercury detections in the SSA. Most of the detections were in samples from Upper and Lower Derby Lakes (54 detections). The highest concentrations of mercury were detected in samples from Upper Derby Lake, where the Section 1 ditch system discharged into the lake (up to 18 ug/g). Mercury was present in about half as many samples in lower concentrations (14 detections) in samples from Lake Ladora. Concentrations ranged up to 2.0 ug/g in samples from the south-central portion of the lake. Mercury was not detected in Lake Mary, Eastern Upper Derby Lake, or Rod and Gun Club Pond.

In general, mercury was detected primarily in the surface intervals of all the lake samples. For example, the 0 to 2 ft depth interval contained 68 percent of all mercury detected in Upper Derby Lake, 85 percent in Lower Derby Lake, and 93 percent in Lake Ladora.

In the Section 1 and 2 ditches and the overflow basin in Section 3, mercury was detected in 27 samples, constituting 19 percent of all samples in which mercury was detected in the SSA. Concentrations ranged from 0.053 to 0.86 ug/g. Mercury was detected in 12 samples in the Section 1 drainage ditches, ten samples in the Section 2 drainage ditches and five samples in the Section 3 ditch and overflow basin. In the Section 1 and 2 ditches and the overflow basin, mercury was detected two to five times more frequently in surface soils (0 to 2 ft) than in the next lower interval (2 to 5 ft).

In Section 11 and 12 buried lake sediments, mercury was detected in 41 samples, which represented 29 percent of all mercury detected in the SSA. Concentrations of mercury from this subarea ranged from 0.054 to 2.3 ug/g and were widely distributed. Mercury was detected most often in the 2 to 5 ft depth interval and least often in the deepest intervals sampled. This may be a result of the 12 to 24 inch cover of clean soil deposited over both sites

following completion of the dredging activities that led to the sites' establishment. Concentrations also tended to increase slightly to a depth of 2 to 5 ft in the Section 12 sediments but remained fairly constant at all depths in the Section 11 sediments.

Mercury was detected at a low concentration in one sample taken from the Section 1 trash dump. Five samples were detected containing mercury, from surface locations scattered throughout the uncontaminated portions of Section 1.

#### 2.1.3.9 ICP Metals

The ICP metals reported in samples from the SSA include zinc, copper, chromium, lead, and cadmium (Figures SSA 2.1-25 through SSA 2.1-27). They were detected predominantly in samples from the lakes area and the Section 2 drainage ditch system. Lead and zinc were detected at their highest concentrations in samples from Upper Derby Lake, Lower Derby Lake, Lake Ladora, and at the 0 to 2 ft depth interval from the ditches. Copper was detected at its highest concentrations in samples from Lower Derby Lake, Lake Ladora, and the Section 2 drainage ditch system (0 to 2 and 2 to 5 ft depth intervals). Chromium was detected at its highest concentrations in samples from Lower Derby Lake and in the 0 to 2 ft depth intervals of the Section 2 drainage ditch system. Cadmium was detected infrequently within the SSA. It was found in samples from Lower Derby Lake and Lake Ladora, the Section 2 drainage ditches and the ditch and overflow basin (Site 3-2/3-3) and the Section 12 buried lake sediments (Site 12-1).

Approximately 535 analyses were conducted for each of these five analytes. Zinc was detected in 530 samples, copper in 367 samples, chromium in 344 samples, lead in 218 samples, and cadmium in 13 samples. The concentration ranges for the analytes were: cadmium at 0.98 to 1.9 ug/g ; chromium at 0.12 to 150 ug/g; copper at 5.6 to 99 ug/g; lead at 10 to 1,200 ug/g; and zinc at 11 to 180 ug/g.

Cadmium was detected sporadically and was not detected above its indicator range in the SSA. The frequency of occurrence above the detection limits for



the remaining four ICP metals is widespread; however, many of the detections were recorded at concentrations below or within, but not above, the upper end of each of the metals indicator ranges. The following table summarizes the frequency at which concentrations of each analyte exceeded the upper limits of its indicator range relative to the total number of samples in which it was detected.

Percent Frequency of Detections Above Upper Limit Indicator Level (IL)

Analyte	IL (ppm)	0 to 2 ft	2 to 5 ft	Greater than 5 ft
Cadmium	1.0 - 2.0	0	0	0
Chromium	25 - 40	0.58	0	0
Copper	20 - 35	3.0	0.54	0
Lead	25 - 40	12	2.3	0
Zinc	60 - 80	4.3	0.75	0.38

As the table shows, most metals were detected at concentrations considered to be naturally occurring with respect to the soil types in which they were detected. Zinc was detected at concentrations above its indicator range throughout the SSA. The highest concentrations were recorded in samples collected from the lakes and ditches. In the lakes, the highest zinc concentrations were localized in the southeastern portion of Upper Derby Lake and in the deeper, southwestern portion of Lower Derby Lake. In Lake Ladora, the highest concentrations were in the central portion of the lake. Zinc was detected consistently throughout Sections 1 and 2 ditches. In all cases, zinc tended to be most concentrated in the 0 to 2 ft depth intervals, although some high concentrations were detected at the 4 to 5 ft depth intervals.

Copper was detected in about 69 percent of the samples analyzed from the SSA. As with zinc, the number of samples containing copper above its indicator range tended to be most prevalent in the lakes and ditches. Lower Derby Lake, Lake Ladora, and the Section 2 drainage ditch systems contained the highest concentrations of this metal. In Lower Derby Lake, although the metal was detected most often in the 0 to 2 ft depth interval, its range of

concentration was greater in the 2 to 5 ft depth interval. In Lake Ladora, copper was detected in its greatest abundance in the 0 to 2 ft depth interval. In both lakes, detection of copper decreased dramatically below a depth of 5 ft. In the Section 2 ditch systems, copper was detected most often in the 0 to 2 ft and greater than 5 ft depth intervals. The highest concentrations of the metal occurred in the surface interval.

Chromium was detected in about 65 percent of the samples analyzed throughout the SSA, but was recorded most often in samples collected from Lower Derby Lake and the Section 2 drainage ditch system. In Lower Derby Lake, the metal was detected in all sampling intervals, but tended to be most concentrated in the 0 to 1 ft depth interval. In the Section 2 ditch systems, distribution of chromium was the same as in Lower Derby Lake. Concentrations of the metal were the highest in the 0 to 2 ft depth interval.

Lead was detected in approximately 41 percent of the samples analyzed from the SSA. It was detected above its indicator range most frequently in Upper and Lower Derby Lakes and Lake Ladora, the Section 2 drainage ditch systems, and in isolated locations within nonsource areas of Section 1. In Upper Derby Lake, lead was essentially confined to the 0 to 2 ft depth interval but was detected below its indicator range in the 2 to 5 ft interval. Lead was detected most often in Lower Derby Lake, at concentrations above its indicator range in the 2 to 5 ft depth interval. The 0 to 2 ft and greater than 5 ft depth intervals contained lead concentrations within its indicator range. In Lake Ladora, lead was detected in concentrations above its indicator range only in the 0 to 2 ft depth interval. The frequency of detections decreased with depth to very few below 2 ft to none at all below 5 ft. The Section 2 drainage ditch systems contained the highest levels of lead found in the SSA (concentrations up to 1,200 ug/g). These samples were collected from the 0 to 2 ft depth interval in Sand Creek Lateral east of Lake Ladora. The frequency of lead detections decreased by about 40 percent below a depth of 2 ft, and concentrations decreased to within its indicator range below 5 ft. Lead was detected sporadically in samples from northern portions of nonsource areas in Section 1. The metal was detected above its indicator range only in the 0 to 2 ft depth interval. The average concentration, however, was well below its indicator range.

Cadmium was detected in less than 5 percent of the samples analyzed in the SSA. The metal was never detected above its indicator range in SSA soils.

#### 2.1.3.10 Nontarget Compounds

The RI nontarget and unknown compounds detected in the SSA soils and sediments were reviewed for their repeatability. Possible identification from other hazardous compound lists or appendices was additionally examined. In general, information on unknowns is limited for soils and sediments. Identification of all compounds is by mass spectral fragmentation patterns taken from GC/MS instrument analysis.

Detection of these compounds is through ionization of the compound which produces a fragmentation pattern, or signal. Each signal belongs to one or more compounds. To identify the compound, its signal is compared to the signal of a known compound; this unknown compound is called a standard.

Difficulties arise when patterns occur from compounds not identifiable from the known standards. The signal or fragmentation pattern of these unknown compounds can be compared to a library consisting of thousands of patterns containing most priority pollutants and common chemicals. The use of such information plays an important note in accounting for fragmentation patterns seen during analysis of RI samples and contains compounds not on the USATHAMA methods Target Compound List (TCL).

Many specific compounds identified are not RI target compounds, and are placed in their respective chemical groupings. The largest groups of compounds found are phthalates, hydrocarbons (saturated and unsaturated), alcohols and aldehydes. These compounds are ubiquitous in the environment or as combustion by-products. They may also be found in the laboratory as contaminants from extraction or analytical procedures.

A small group of Polynuclear Aromatics (PNA) were also detected. Each compound occurred only once and was sometimes impossible to distinguish from another PNA with the same GC/MS fragmentation pattern. Pesticides other than the target pesticides were detected only once, such as chlordene and

endosulfan. A few aromatic hydrocarbons were also detected such as isomers of benzene and naphthalene. These compounds occurred more than once but not at any frequency.

Overall, no one specific compound was repeatedly detected. Individual CARs and Phase II Data Addenda cite specific concentrations of nontarget compounds detected in the SSA.

#### 2.1.4 Summary of Previous Investigations

A number of soil and sediment investigations in the SSA have been conducted since the early 1950s. Early investigations by Shell and the Julius Hyman Company were initiated in response to specific spill incidents originating in South Plants or by severe cases of waterfowl and fish mortality. Later investigations concentrated specifically on identifying contaminants in Upper and Lower Derby Lakes, Lake Ladora and Lake Mary, and as part of these studies, the Section 1 ditch systems leading to the Derby Lakes. Subsequent studies investigated the two areas in Sections 11 and 12 used for the disposal and burial of lake sediments. Data presented in this subsection are reported to the same number of significant figures as presented in the original reports.

The earliest recorded investigations of the lakes occurred in 1951 and continued until 1956. The lakes were monitored for a period of time for pH levels due to reported high pH readings caused by the inadvertent release of a caustic solution from a chlorine plant operated by Julius Hyman Company (MKE, 1987). During the same time period, the Army suspected that the lakes were also contaminated with organic compounds from Hyman's manufacturing processes. The first documented occurrence of pesticides in the lakes was in 1952, when Shell (which had acquired Hyman's lease) detected dieldrin and aldrin at 1.0 and 68 ug/g respectively, in lake surface waters and foam (MKE, 1987). Later studies by the USFWS confirmed these findings, along with reported occurrences of wildlife mortality (Jensen, 1955; Finley, 1959). Prior to the removal of lake sediments in 1964 and 1965, the USFWS conducted an intensive sediment sampling program in the lakes. Results of over 800 samples collected by both the USFWS and later by Shell indicated the presence of aldrin, dieldrin, endrin, and isodrin in Upper and Lower Derby Lakes

sediments at concentrations ranging up to 180 ug/g, 13 ug/g, 8.3 ug/g, and 10 ug/g, respectively (Sheldon & Crabtree, 1965/RIC 87091R03; MKE, 1987/RIC 88011R03). Subsequent Shell analyses of sediments from Lake Ladora following the refilling of the Lake confirmed that sediments were still contaminated with up to 30 ug/g aldrin in the inlet channel leading from Lower Derby Lake. This area was subsequently scraped and a new channel constructed (MKE, 1987/RIC 88011R03).

Studies conducted in 1982 and 1983 by the USAEWES found aldrin, dieldrin, and mercury widely distributed in Upper and Lower Derby Lakes and Rod and Gun Club Pond, as well as in adjoining channels connecting the lakes (Myers et al., 1983/RIC 84086R01).

Mercury was detected primarily in the surface intervals of both lakes. Dieldrin and aldrin detections were widespread in both lakes, in the 0 to 1 and 1 to 2 ft depth intervals. Generally, the concentrations decreased with depth or were found in the sediments in shallow basins. The highest concentrations of these analytes tended to occur at inlets and outlets of the lakes, as well as the center of each lake where water levels tended to be deepest. The highest detected concentrations of these analytes were: aldrin at 100 ug/g; dieldrin at 96 ug/g; and mercury at 3.3 ug/g. The results of these analyses are shown in Appendix SSA B (Figures SSA-B-2 through SSA-B-5), Historical Data.

Like the 1982 USAEWES study of the Derby Lakes, a 1983 investigation of Lakes Ladora and Mary studied the distribution and concentration of aldrin, dieldrin, and mercury in sediments (Myers & Gregg, 1984/RIC 86192R01). In addition, endrin was also studied in the two lakes. Aldrin was the most ubiquitous of the analytes, detected in 81 percent of the 145 samples in the two lakes analyzed and in nearly all of the surface interval samples analyzed (98 percent). The other two organochlorine pesticides (dieldrin and endrin) were also detected most frequently in surface intervals. The results of the study found widespread distribution of the three organochlorine pesticides (dieldrin, endrin, and aldrin) in Lake Ladora, with the highest concentrations detected in the inlet channel to the lake and the inlet pool adjacent to 6th

Avenue (less than 2 ug/g). Mercury was detected in over 60 percent of the samples analyzed. This metal was detected at its highest concentration (0.5 ug/g) in the central portion of the lake. As was observed in the Derby Lakes, concentrations of these analytes tended to be highest in the surface intervals. In addition to these four compounds, other analytes detected in isolated locations included methylene chloride, DDT, diethyl phthalate, phenanthrene, dibutyl phthalate, butylbenzyl phthalate, and bis(2-ethylhexyl) phthalate. In Lake Mary, aldrin, dieldrin, endrin, and mercury were detected, all at concentrations below 1.0 ug/g. Concentrations were widespread, with no particular pattern of distribution or concentration gradient with regard to water depth. Methylene chloride, phenanthrene, and bis(2-ethylhexyl) phthalate were also detected at relatively low concentrations. The results of this study are shown on Appendix Figures SSA-B-6 and SSA-B-7 in Appendix SSA B, Historical Data.

Bergersen and others (1984/RIC 84142R01) collected several samples from Lake Ladora for chemical analysis. Results indicated that aldrin and dieldrin were present at low concentrations and that mercury was present throughout the lakes at relatively low concentrations (below 1 ug/g). In addition, the sediments in the lakes were dated, using Cesium-137 techniques. The dating study detected sediments that had been deposited as early as 1958, indicating that in some portions of the lakes, dredging was not thoroughly completed during the 1964-65 cleanup. Based upon the observations made of sediments during the sampling program, the depth of the sand/silt interface noted on logs indicated that the sediment dating program was accurate to within one to two years of its actual deposition. Results of the sediment dating program indicated that in Lower Derby Lake, organochlorine peak concentrations occurred in the 9 to 16 inch depth range. These depths corresponded to a depositional period between 1962 and late 1971. Mercury concentrations peaked at depths ranging from 13 to 17 inches corresponding to a depositional period from 1961 to mid-1965. In Lake Ladora, organochlorine pesticide concentration peaks occurred in the 8 to 10 inch depth range, deposited between 1958 to 1968. Mercury concentrations peaked between depths of 1 to 8 inches, which corresponded to a wide period of time, 1969 to 1982. The USFWS concluded its sedimentation study by stating that "since about 1970-1972 the situation in

both Ladora and Lower Derby Lakes has been fairly stable with no abrupt changes in contaminant concentrations occurring."

As part of the investigation of the Derby Lakes, USAEWES placed numerous borings in the Section 1 ditch system leading from the South Plants area and exiting into Lower Derby Lake (Appendix Figure SSA-B-1). The results of the study found widespread contamination by aldrin and dieldrin in all ditch intervals sampled to a depth of 2 ft. The highest concentration of aldrin was 53 ug/g, detected near the mouth of the westernmost ditch as it enters the northwestern corner of Lower Derby Lake. Dieldrin was detected at its highest value of 0.32 ug/g at this same location. These contaminants were detected in both the 0 to 1 and 1 to 2 ft depth intervals, although the highest concentrations detected were found in samples from the surface intervals.

In late 1964 and early 1965 when the Derby Lakes and Lake Ladora were dredged (see Section 1.3, History), the excavated sediments were deposited in two areas along 6th Avenue: one in Section 11 and the other in (in two parts) Section 12. These sediments were studied in 1982 by Geraghty and Miller (1982/RIC 81342R06) and USAEWES (Myers et al., 1983/RIC 84086R01) and in 1985 by Dames and Moore (1985/RIC 85218R01).

These studies detected widespread distribution of the following analytes in Section 12 sediments:

Analyte	Highest Concentration
	<u>Reported (ug/g)</u>
Aldrin	39
Dieldrin	21
Endrin	3.0
Mercury	3.7
Chlordane	2.0
DDE	0.8
DDT	0.6

These analytes were detected throughout the Section 12 sediments, as well as in the ditch carrying overflow water from Lower Derby Lake to adjacent Rod and Gun Club Pond. The majority of the contaminants listed above were detected at depths from 5 to 15 ft. The deepest contamination (of an unidentified nature) was detected, according to Dames and Moore, at a depth of 22 ft. Several

other target and nontarget compounds were detected but at very low concentrations.

Of the Section 11 sediments studied by Geraghty and Miller (1982/RIC 81342R06, dieldrin was present in the surface interval (0 to 2 ft) of a boring sampled in the northeastern portion of the site. Mercury was also detected in the 2 to 3 ft depth interval of this boring. Both analytes were detected at concentrations below 1 ug/g. No other analytes were detected during this study. The Dames and Moore study analyzed over 70 samples for aldrin, dieldrin, endrin, mercury, and semivolatile organic compounds. No aldrin, dieldrin, endrin, or other semivolatile analytes were detected. Mercury was found in eight borings at concentrations as high as 1.3 ug/g and ranging in depth to 9 ft. The results of the analyses from the USAEWES (1984/RIC 85133R04) and Dames and Moore investigations are shown on Appendix Figures SSA-B-8 through SSA-B-10, in Appendix SSA B, Historical Data.

In summary, previous investigations conducted in areas studied in the SSA corroborates the analytical results obtained during Phases I and II of the RI program. Lakes and ponds receiving inflow from South Plants tended to contain the highest concentrations of potential contaminants. The most numerous samples containing the highest concentrations of organochlorine pesticides and metals were detected in ditches, inlets to lakes, the deepest portions of the lakes, and areas of channelized flow.

## 2.2 SURFACE WATER CONTAMINANTS

Surface water samples have been analyzed from 34 locations in the SSA during various investigations (Table SSA 2.2-1). This discussion includes data from the 34 sampling locations and five other locations in the South Plants ditches that drain into the SSA. Each investigation focused on a different suite of analytes, all of which are listed in Appendix SSA A, Part II, except those from the historical investigation. The historical surface water data are used to support more recent data where applicable and supplement data gaps where possible, but these data are not presented independently. A summary of historical data is included in ESE's Final Initial Screening Program Report, 1986. A comparison of the historical data to ESE's more recent data is also



given in this report. (Table SSA 2.2-1 provides a more detailed explanation of the historical investigation.)

The analytical data from these investigations (except historical data) are presented in Table SSA 2.2-2, which summarizes the analytes that were detected in these investigations. There are two factors to consider when comparing the surface water data from the Task 4/44 (RI) and previous investigations. Under the RI investigations, samples were analyzed for a wider range of analytes and, more importantly, were sampled over a greater area than under the previous investigations. The apparent high frequency of detections and elevated concentrations associated with the previous investigations are results of these factors. In the Spain and Gregg (1983) and Shell (1980) investigations, samples were collected from near suspected sources of contamination in South Plants where higher concentrations of contaminants would be expected in surface water. RI samples were not only collected near South Plants but also from nonsource areas throughout the SSA where lower concentrations and nondetectable concentrations are expected and reported for the samples collected. The other two previous studies used in this report focused on areas within the SSA. In these areas, analyte concentrations tend to be lower and have much lower frequencies of detection, as is expected. Finally, the RI investigations included a much larger range of analytes which may also contribute to lower frequencies of detection reported with the RI data.

Table SSA 2.2-1 presents contaminants by analytical group and summarizes their occurrences in terms of frequency of detections; it also provides the concentration ranges for these analytes. The detection limits and reporting limits for an analyte vary to some degree between investigations. Appendix SSA A-2, Part II gives a list of all SSA analyte detection limits and reporting limits. In general, the majority of the data reported has the same reporting limit or detection limit.

The following subsections discuss surface water contaminants by analytical group and sampling locations. Figures SSA 2.2-1 through SSA 2.2-9 depict the areal distribution of each analyte group detected, along with general descriptions of detection levels. These levels were determined by summing the geometric means of the individual analytes within a group.

The geometric means include data that are below certified reporting limits (BCRL). A numeric value was not assigned to data BCRL in calculating the geometric mean; rather, the geometric mean is "adjusted" by only including values of data above CRL and then multiplying that mean by the factor (n/s), where "n" equals the number of detections reported at a sampling site, and the "s" equals total number of samples taken at that site. For example, four samples were taken from sampling location ESE 11-3 and analyzed for tetrachloroethylene. Three of those samples had detections of the analyte and one did not. The adjusted geometric mean, therefore, was only calculated for the detected values and then multiplied by the factor 3/4. The means of the individual analytes are then summed for that analytical group and plotted as various sized dots.

The following calculations demonstrate how the adjusted geometric mean is calculated:

$$\text{Adjusted Geometric Mean} = (n/s) (a_1 \times a_2 \times a_3 \times \dots a_n)^{1/n},$$

where n = number of hits,

s = number of samples collected, and

a = concentration of the n<sup>th</sup> hit.

#### 2.2.1 Distribution of Analytes

The analytes discussed in this section represent those that were detected in surface water samples collected from throughout the study area, as shown in Figures SSA 2.2-1 through SSA 2.2-9. However, little information is available about surface water contamination in the central portion of the study area where there are no surface water containments (lakes, ponds, basins, and ditches). In the SSA, contaminants were detected most frequently in samples from the Sections 1 and 2 ditch systems. Contaminants were also detected in the other ditches, in the lakes, and less frequently, in the ponds and basins. All data in this section have been rounded to two significant figures and are reported in micrograms per liter (ug/l). Figures are not presented for analytical groups where detections in that group are scattered or sparse.

#### 2.2.1.1 Volatile Halogenated Organics

Six volatile halogenated organics (VHO) from this group were detected in samples from the SSA, including chloroform, 1,1,1-trichloroethane, carbon tetrachloride, tetrachloroethylene, and chlorobenzene (Figure SSA 2.2-1). Methylene chloride is shown separately on Figure SSA 2.2-2.

In 79 samples analyzed for chloroform, 16 contained detectable amounts of chloroform at concentrations ranging from 1.0 to 130 ug/l, excluding two anomalous concentrations. These anomalous concentrations of 3,400 and 4,800 ug/l were detected in samples collected from South Plants ditches in May 1983, at sampling sites SG1 and SG8. Location SG8 was sampled four times in a 51-day period in 1983. Chloroform was detected each time as follows: 7 ug/l, 3,400 ug/l, 64 ug/l, and 130 ug/l. The samples reporting chloroform at 3,400 ug/l and 64 ug/l were both collected on the same day. Likewise, the five samples collected from location SG1 showed similar results with a detection of 4,800 ug/l of chloroform reported in a sample collected the same day as the sample reporting 3,400 ug/l collected from SG8. Nearby samples collected in 1980 from sampling locations SC3 and SC8 showed no elevated levels of chloroform; moreover, downstream samples collected in 1986 during the RI at sampling location ESE 1-3 did not report chloroform. These elevated detections from SG1 and SG8 are considered to be one-time occurrences and, therefore, were excluded from the VHO distribution map and the summary tables (Table SSA 2.2-2). Chloroform was detected in samples collected from the Section 1 and 2 ditches, primarily those just within the border of South Plants. It was also detected once in the overflow basin west of Lake Mary. Historically, chloroform was also detected in Section 1 ditches.

Samples taken from the ditches north of Upper Derby Lake contained the only occurrences of tetrachloroethylene, carbon tetrachloride, and chlorobenzene. Samples were collected, however, from throughout the SSA; 78 of which were analyzed for tetrachloroethylene, 79 for carbon tetrachloride and 78 for chlorobenzene. In these samples, the following were found: three detections of carbon tetrachloride ranging in concentration from 16 to 170 ug/l, two detections of tetrachloroethylene ranging in concentration from 4.0 to 5.0 ug/l, and one detection of chlorobenzene at a concentration of 1.0 ug/l.

1,1,1-Trichloroethane was detected in two of 60 samples collected. The samples were collected from the Peoria Street. Interceptor Ditch and had concentrations of 1.9 and 2.9 ug/l.

Methylene chloride was detected in seven of 67 samples collected, with concentrations ranging from 0.01 to 300 ug/l. Methylene chloride occurred in the ditches along the study area's southern border, as well as in Havana Pond, Lake Mary, and Lake Ladora (Figure SSA 2.2-2).

#### 2.2.1.2 Volatile Hydrocarbons

The volatile hydrocarbons (VHC) detected in samples from the SSA include, dicyclopentadiene, methylisobutyl ketone, 4-hydroxy-4-methyl-2-pentanone, and 2-pentanone (Figure SSA 2.2-3).

Dicyclopentadiene and methylisobutyl ketone were detected in the ditches located inside the South Plants border feeding into the SSA. From 77 samples analyzed, dicyclopentadiene was detected in three samples at concentrations ranging from 20 to 30 ug/l, and methylisobutyl ketone was detected in two of 75 samples analyzed with concentrations ranging from 12 to 40 ug/l.

4-Hydroxy-4-methyl-2-pentanone and 2-pentanone were only investigated in SSA surface waters by Dames and Moore (1985/RIC 85218R01). These analytes were detected in one of the Dames and Moore samples collected from the Peoria Ditch. This sample contained 2.0 ug/l of 4-hydroxy-4-methyl-2-pentanone and 3.0 ug/l of 2-pentanone.

#### 2.2.1.3 Volatile Aromatic Organics

The volatile aromatic organics (VAO) detected in samples from the SSA include benzene and toluene as shown in Figure SSA 2.2-4. Toluene was detected in three of 78 samples in concentrations of 3.0 to 22 ug/l. One sample was collected from the Peoria Ditch, one from the Section 1 ditch system, and one from the southern border of the SSA.

Like chloroform, benzene was also detected at elevated concentrations of 2,000 ug/l and 3,500 ug/l at the same sampling locations in the South Plants area (SG1 and SG8) and from the same sampling period (May, 1983). Exclusive

of these two samples, benzene concentrations varied from 1.0 to 40 ug/l in 9 of 77 samples analyzed for benzene. Most detections of benzene were in samples collected from the Section 1 ditches near South Plants; benzene was also detected in Havana Pond, Lake Ladora, and in Section 2 ditches near the South Plants border.

#### 2.2.1.4 Organosulfur Compounds

Benzothiazol was the only organosulfur compound (OSC) detected. Three of 28 samples analyzed for benzothiazol contained the analyte. These samples were collected from along the southern border of the study area and had concentrations ranging from 1.8 to 12 ug/l (Figure SSA 2.2-5).

#### 2.2.1.5 Organophosphorous Compounds

From the organophosphorous compounds (OPH), dimethylmethyl phosphonate was the only compound detected in two of 65 samples analyzed. These detections were reported in two samples from the ditch north of Upper Derby Lake (sampling site SC3) at concentrations of 3.0 and 4.0 ug/l. Because of the infrequent occurrence of this analyte, no separate figure was made. Historically, diisopropylmethyl phosphonate was detected along the southern border of the SSA, however, in more recent investigations its occurrence was not repeated in this area.

#### 2.2.1.6 Dibromochloropropane

Three of 81 samples analyzed contained DBCP. These three samples were collected from two sampling sites in Section 1 ditches, north of the Derby Lakes (Figure SSA 2.2-6). Concentrations ranged from 0.28 to 0.83 ug/l. Historically, DBCP was also detected in surface water samples from these locations at 4.9 ug/l.

#### 2.2.1.7 Organochlorine Pesticides

Of the analytes detected in surface water samples collected from the SSA, those from the organochlorine pesticide (OCP) group were detected most often (Figure 2.2-7). In particular, those analytes include dieldrin, aldrin, endrin, and isodrin. Throughout the study area, 46 detections from this group were reported from 11 sampling sites. The majority of these detections were

found throughout the northern portion of the study area in the ditches above Lake Ladora, Lake Mary, and the Derby Lakes. However, three samples from the southern portion of the study area also contained low levels of OCPs (less than 1.0 ug/l). Historically, OCPs were detected throughout the study area. More recent investigations, however, have not reported similar findings, except for a few coincidental detections of OCPs in the ditch feeding into Lower Derby Lake.

Dieldrin was detected in 20 of 90 samples collected, aldrin was detected in 14 of 88 samples collected, endrin was detected in six of 87 samples collected, and isodrin was detected in six of 74 samples collected. Concentrations ranged as follows: aldrin, from 0.09 to 3.7 ug/l; endrin, from 0.08 to 4.4 ug/l; dieldrin, from 0.02 to 30 ug/l; and isodrin, from 0.22 to 5.6 ug/l.

#### 2.2.1.8 Arsenic

Arsenic was detected in nine of 32 samples collected from throughout the study area (Figure SSA 2.2-8). This analyte was detected primarily in samples taken from the ditches in the SSA at concentrations of 2.6 to 16 ug/l. It was also detected, however, in the overflow basin west of Lake Mary.

#### 2.2.1.9 ICP Metals

The metals detected in the SSA include cadmium, chromium, copper, lead, and zinc. These ICP metals were found in the ditches along the southern half of the SSA (Figure SSA 2.2-9). Copper was detected in seven of 37 samples collected and chromium in four of 32 samples collected. The concentrations of the analytes ranged from 3.0 to 30 ug/l and 6.0 to 49 ug/l, respectively. Zinc and lead each occurred in six of 32 samples analyzed for both metals. Concentrations ranged from 22 to 190 ug/l for zinc and 11 to 76 ug/l for lead.

### 2.3 GROUNDWATER CONTAMINANTS

Analytical data from 53 wells in the SSA and various other wells in adjacent study areas were compiled and used to define the nature and distribution of contaminants in groundwater. Recent groundwater investigative reports by ESE and MKE are the primary sources of information used in preparing this section.

Although the Water Remedial Investigation (RI) by ESE used data from the third quarter 1987 (Spring 1987), data were also collected during the 1986 fiscal year by ESE. Thirty-four wells in the SSA were sampled during both of these fiscal years, under Tasks 4 and 44. Analytical data from these wells and ten peripheral wells in the SPSA and the ESA were used to define the distribution of contaminants and to support the contamination assessment for the SSA. Data from nine Shell wells sampled during the summer of 1988 in and peripheral to the SSA were also used to supplement ESE's data. In addition, historical groundwater data for the years prior to 1986 were compiled from the USATEAMA database. The information from this database was reviewed and compared to current RI data. The historical data tend to be scattered, in that they do not show trends. Not all wells were sampled consistently and not all analytes were investigated in every well. Since this section focuses only on recent contaminant distributions, the historical data has been incorporated only where necessary (i.e., to fill in data gaps). Appendix SSA B, Part II, presents a complete list of the historical data prior to 1986 for the SSA.

Groundwater samples, collected from wells in and near the SSA, were screened in five separate water bearing zones (WBZ) including WBZ 1A, WBZ 1, WBZ 2, WBZ 3, and WBZ 4. WBZ 1A represents the alluvial water bearing zone, and WBZ 1 through WBZ 4 represent consecutively deeper water bearing zones in the Denver Formation. Section 1.5.3 provides a more detailed discussion of the water bearing zones.

The information in this section is presented according to the different groups of analytes investigated in groundwater by ESE and MKE. ESE investigated 50 analytes as well as pH and specific conductivity. Of the 50 analytes, only a few were detected and even fewer were detected more than once. The list of analytes discussed in this section represents the analytes detected in the groundwater as reported by ESE and MKE. This section also includes a general description of the vertical distribution of the contaminants with respect to the five water bearing zones and includes a detailed description of each analytical group and its areal distribution in the SSA. Table SSA 2.3-1 outlines the contaminants by analytical group and details the frequency and range of detections by water bearing zone and well. The reporting limits for

the analytes investigated are provided in Appendix Tables SSA-3. These tables also give the adjusted geometric mean for each of the analytes in a group. The adjusted geometric means include data that are BCRL. A numeric value was not assigned to data BCRL in calculating the geometric mean; rather, the geometric mean is "adjusted" by only including values of data above CRL and then multiplying that mean by the factor  $(n/s)$ , when "n" equals the number of detections reported at a sampling site, and "s" equals total number of samples taken at that site. For example, four samples were taken from Well 02035 and analyzed for tetrachloroethylene. Three of those samples had detections of the analyte and one did not. The adjusted geometric mean, therefore, was only calculated for the detected values and then multiplied by the factor  $3/4$ .

Figures SSA 2.3-1 through 2.3-19 illustrate the areal distributions of the analyte groups by water bearing zone. In the figures, values for detected analytes from a particular analyte group are summed for a specific well.

#### 2.3.1 Distribution of Analytes

As previously discussed, the wells sampled by ESE and MKE were screened in five separate water bearing zones. Because the number of wells screened in each zone varied, some zones were sampled more extensively than others. Eleven wells were screened in WBZ 1A, 21 wells in WBZ 1, nine in WBZ 2 and WBZ 3, and three wells in WBZ 4. Contaminants were detected in 11 of the 11 wells in WBZ 1A, 19 of the 21 wells in WBZ 1, nine of the nine wells in WBZ 2, nine of the nine wells in WBZ 3, and three of the three wells in WBZ 4 (Table SSA 2.3-1).

The majority of groundwater samples were collected from wells located north of the lakes area. A few samples were taken from wells located along the southern borders of Sections 1 and 2, from one well cluster in Section 11, and from one well cluster in Section 12. There is no available well data for the northern portion of these sections or from along the southern border of the study area. In addition, only wells in the northern portion of the study area were screened and sampled in WBZ 4. In the following subsections, figures are not presented for analytical groups where detections in that group are scattered or sparse.



#### 2.3.1.1 Volatile Halogenated Organics

The volatile halogenated organics (VHO) detected in the SSA groundwater include 1,1,2-trichloroethane, 1,1-dichloroethane, 1,2-dichloroethylene, 1,1-dichloroethylene, carbon tetrachloride, chloroform, chlorobenzene, tetrachloroethylene, trichloroethylene, and methylene chloride. These analytes were detected in all five water bearing zones but were found most frequently in WBZ 1 and WBZ 2. The distribution of these analytes was laterally and vertically more widespread than the other organic compounds, although they were more commonly detected in samples from wells located in the northern half of the study area (Figures SSA 2.3-1 through SSA 2.3-3).

Of the VHOs present in the groundwater, chloroform was detected most often and was reported in samples collected from all five water bearing zones.

Chloroform was detected in 36 samples collected from 19 wells in concentrations ranging from 1.4 to 430 ug/l. Seven samples were collected from wells screened in WBZ 1A, 16 samples from wells screened in WBZ 1, 10 samples from wells screened in WBZ 2, and one sample each from two wells screened in WBZ 3 and WBZ 4. 1,1-Dichloroethane was detected in 17 samples. Three samples were collected from wells screened in WBZ 1A, nine samples were collected from wells screened in WBZ 1, and five samples were collected from wells screened in WBZ 2. Concentrations ranged from 1.4 to 72 ug/l.

Trichloroethylene was detected in 12 samples in WBZ 1A, WBZ 1, and WBZ 2 in concentrations ranging from 0.96 to 11 ug/l. One sample was collected from a well screened in WBZ 1A, six samples were collected from wells screened in WBZ 1, and five samples were collected from wells screened in WBZ 2.

Chlorobenzene was detected in ten samples from nine wells in concentrations ranging from 0.71 to 1000 ug/l. From the ten samples with chlorobenzene detections, three samples were collected from wells screened in WBZ 1A, five samples were collected from wells screened in WBZ 1, and five samples were collected from wells screened in WBZ 2. Tetrachloroethylene was detected in seven samples at concentrations ranging from 1.4 to 3.8 ug/l. Three samples were collected from wells screened in WBZ 2 and four were collected from wells screened in WBZ 2.

1,1,2-Dichloroethylene was detected in eight samples. One sample was collected from one well screened in WBZ 1A, five samples were collected from wells screened in WBZ 1, and two samples were collected from two wells screened in WBZ 2. Carbon tetrachloride was detected in six samples ranging in concentration from 4.7 to 15 ug/l. Two samples were collected from WBZ 1 and four samples from wells screened in WBZ 2. 1,1,2-Trichloroethane and 1,1-dichloroethylene were detected at 1.1 and 3.9 ug/l in samples from wells screened in WBZ 2 and WBZ 1A, respectively. 1,2-Dichloroethane was detected in one sample at a concentration of 8.0 ug/l.

Methylene chloride was detected in two samples, at concentrations of 6.1 and 8.1 ug/l, from wells screened in WBZ 2.

#### 2.3.1.2 Volatile Hydrocarbons

Dicyclopentadiene and bicycloheptadiene were the detected compounds from the volatile hydrocarbons (VHC) analyte group. Dicyclopentadiene was detected in one sample from a well screened in WBZ 1A at 13 ug/l, and in six samples from wells screened in WBZ 1 at elevated concentrations ranging from 200 to 3,400 ug/l. Three samples from wells screened in WBZ 1 contained bicycloheptadiene in concentrations ranging from 5.4 to 7.1 ug/l. Both compounds were generally detected in the northern half of the SSA (Figure SSA 2.3-4). The elevated concentrations of dicyclopentadiene were reported in wells adjacent to the SPSA.

#### 2.3.1.3 Volatile Aromatic Organics

The volatile aromatic organics (VAO) detected in the SSA groundwater include benzene, ethylbenzene, toluene, m-xylene, and o- and p-xylene (Figure SSA 2.3-5). Benzene was detected in 15 samples collected from 12 wells during the recent groundwater investigations (Figures SSA 2.3-6 through SSA 2.3-8). Concentrations varied from 1.9 to 900,000 ug/l. The elevated benzene detections included 60,000 ug/l for Well 01557; 80,000 for Well 01556; 150,000 to 330,000 ug/l for Well 01014; and 900,000 ug/l for Well 01558. These wells are all located near the SPSA border and the north central portion of Section 1; they are discussed in more detail in Section 3. From all samples collected, benzene was detected in 11 samples from wells screened in WBZ 1, in

two samples from wells screened in WBZ 2, and in two samples from wells screened in WBZ 3.

Other compounds from this group were detected in samples collected from one well screened in WBZ 1 (Well 01014, see Figure SSA 1.5-3) and contained the following compounds: ethylbenzene in two samples at concentrations of 270 and 280 ug/l; toluene in three samples at concentrations ranging from 720 to 830 ug/l; m-xylene and o- and p-xylene in three samples at concentrations ranging from 700 to 1,600 ug/l and 1,300 to 2,600 ug/l, respectively.

#### 2.3.1.4 Organosulfur Compounds (Mustard-Agent Related)

Detected organosulfur compounds (OSCM) include dithiane and 1,4-oxathiane. Dithiane was detected in two samples collected from a well screened in WBZ 1 near the South Plants border, in concentrations of 1.6 and 2.2 ug/l. 1,4-Oxathiane was also detected in a well screened in WBZ 1 near the South Plants border at a concentration of 4.3 ug/l.

#### 2.3.1.5 Organosulfur Compounds (Herbicide Related)

From this group (OSCH), chlorophenylmethyl sulfone, chlorophenylmethyl sulfoxide, and chlorophenylmethyl sulfide were detected in the SSA groundwater. These compounds were present in wells screened in four of the five WBZs and located north of the lakes near the South Plants border. Chlorophenylmethyl sulfone was detected in eight samples from wells in concentrations ranging from 3.2 to 160 ug/l. Three samples were collected from a well screened in WBZ 1A, three samples were collected from wells screened in WBZ 1, and two samples were collected from Wells 02039 and 02025 screened in WBZ 3 (see Figure SSA 1.5-3 for location). Chlorophenylmethyl sulfoxide was detected in one sample at concentration of 5.0 ug/l collected from a well screened in WBZ 1. Chlorophenylmethyl sulfide was also detected at 4.1 ug/l in one sample from a well screened in WBZ 2.

#### 2.3.1.6 Organophosphorous Compounds

Of the organophosphorous compounds (OPH), only diisopropylmethyl phosphonate was detected. In the SSA, it was detected in two samples from two wells at

concentrations of 41 and 23 ug/l. The wells are located north and south of Lower Derby Lake and are screened in WBZ 1 and WBZ 2, respectively.

#### 2.3.1.7 Dibromochloropropane

DBCP was detected in groundwater samples collected from six wells screened in four of the five water bearing zones (Figure SSA 2.3-9). It was detected in eight samples at concentrations ranging from 0.14 to 2.8 ug/l. Of these eight samples, one was collected from a well screened in WBZ 1A, five were collected from wells screened in WBZ 1, one was collected from a well screened in WBZ 2, and the remaining sample was collected from a well screened in WBZ 3. Most of the detections of DBCP were reported from wells north of the lakes. One sample, collected from WBZ 3 in a well in Section 12, also reported a detection that is unusual in that most of the organic compounds were detected in Sections 1 and 2 and in WBZ 1A or WBZ 1.

#### 2.3.1.8 Organochlorine Pesticides

The organochlorine pesticides (OCP) detected in the SSA groundwater include aldrin, dieldrin, endrin, DDE, and DDT. Figure SSA 2.3-10 shows the areal distribution of OCPs in WBZ 1A and 1.

Aldrin was detected in three wells that were screened in WBZ 1A, WBZ 1, and WBZ 3 and located in the northwest corner of the study area. Concentrations ranged from 0.07 to 0.29 ug/l. Dieldrin was detected in 17 samples collected from six wells located in the northern half of the study area in concentrations ranging from 0.061 to 2.9 ug/l. Seven samples were collected from wells screened in WBZ 1A, six samples were collected from wells screened in WBZ 1, and four samples were collected from wells screened in WBZ 2. Endrin was present in four samples taken from three wells located near the South Plants Study Area border in Sections 1 and 2 at concentrations ranging from 0.06 to 0.46 ug/l. Three samples were collected from two wells screened in WBZ 1, and one sample was collected from a well screened in WBZ 3.

DDE was detected in two samples from two wells screened in WBZ 1A and WBZ 1 located in the northwest corner of the study area. Detected concentrations were 0.2 and 0.12 ug/l, respectively. DDT was detected in two wells in

Sections 2 and 3, which were screened in WBZ 1A and WBZ 1. Concentrations were reported at 0.13 and 0.24 ug/l.

#### 2.3.1.9 Arsenic

Arsenic was found more often than any other metal, in 15 samples collected from 15 wells. Three samples were collected from wells screened in WBZ 1A, three samples were collected from wells screened in WBZ 1, two samples were collected from wells screened in WBZ 2, four samples were collected from wells screened in WBZ 3, and two samples were collected from wells screened in WBZ 4. Arsenic concentrations in these samples ranged from 4.1 to 20 ug/l. Generally, arsenic was detected throughout the SSA in all water bearing zones (Figures SSA 2.3-11 through 2.3-13).

#### 2.3.1.10 Mercury

Mercury was detected in five samples collected from five wells at concentrations ranging from 0.25 to 0.51 ug/l. One sample was collected from a well screened in WBZ 1 near the SPSA border in Section 2, two samples were collected from wells screened in WBZ 2 north of the lakes, and two samples were collected from wells screened in WBZ 3 north of the lakes (Figures SSA 2.3-14 through SSA 2.3-16).

#### 2.3.1.11 ICP Metals

The ICP metals detected in the SSA groundwater include cadmium, chromium, copper, and lead. In comparison with the organic compounds, these metals were generally more prevalent both vertically and laterally. These metals were detected in all five water bearing zones, but primarily in samples collected from the northern half of the study area (Figures SSA 2.3-17 through SSA 2.3-19).

Cadmium was detected in a well screened in WBZ 1A and in a second well screened in WBZ 3. Concentrations were 12 ug/l and 27 ug/l, respectively. Chromium was detected in 11 samples at concentrations ranging from 6.4 to 37 ug/l. Six of the samples collected were from wells screened in WBZ 1A; one sample from a well screened in WBZ 1; three samples from wells screened in WBZ 2; and one sample from a well screened in WBZ 3. Copper was detected in three

samples collected from three wells screened in WBZ 1A, located south of the Derby Lakes. Concentrations ranged from 8.3 to 30 ug/l.

Lead was detected in five samples collected from four wells located throughout the SSA. Three samples were collected from wells screened in WBZ 1A, one sample was collected from a well screened in WBZ 2, and one sample was collected from a well screened in WBZ 3. Concentrations ranged from 24 to 45 ug/l. Zinc was detected in 39 samples located throughout the study area. Thirteen samples were collected from wells screened in WBZ 1A, 15 from wells screened in WBZ 1, seven from wells screened in WBZ 2, three were collected from wells screened WBZ 3, and one from a well screened in WBZ 4. Concentrations of zinc ranged from 22 to 280 ug/l.

#### 2.3.1.12 Nontarget Compounds

The nontarget analytes detected in groundwater (Water Remedial Investigation Report, Ebasco, 1989) were reviewed for their repeatability, concentration, and chemical grouping in the SSA. (See Section 2.1.3.10 for a description of methods used to identify nontarget compounds). The first chemical group identified was the saturated, long chain hydrocarbons (alkanes) consisting of n-eicosane, n-neneicosane, n-heptadecane, n-nexadecane, n-nonadecane, n-pentadecane, n-tetradecane, docosane, and octadecane. This group was found at concentration levels of 13 ug/l to 670 ug/l in well 03005 in the SSA. The VHC target compound, dicyclopentadiene co-occurs with these hydrocarbons. Nontarget hydrocarbons were also detected in wells in South Plants near the SSA border, but were not detected in the downgradient well 02020 in the SSA. Two unsaturated hydrocarbons (alkenes) were detected at 2400 ug/l and 7700 ug/l in well 01014 in South Plants, near the SSA border. They consist of 1,4-cyclooctadiene and 3-methyl-1,3,5-hexatriene. Again, these hydrocarbons were not detected in the downgradient well 02020. All of these hydrocarbons are by-products of petroleum oils.

Another group detected in or near the SSA were the aliphatic acids; including butyl hexadecanoate, dodecanoic acid, isobutyl octadecanoate, and octanoic acid. These compounds are commonly found in nature as the decomposition products of organic materials. Concentrations were near 10 ug/l for all

detections. Octa decanamide was also detected and also belongs to the group of naturally occurring compounds. All of the above compounds were detected in wells in South Plants near the SSA border and were not detected downgradient in well 02020 in the SSA.

The last group of nontarget compounds are the aromatic hydrocarbons. Napthalene, methylnapthalene, methylethylbenzene, and trichlorobenzene were all detected at concentrations ranging from 800 ug/l to 15,000 ug/l. Some of these concentrations were reported in wells where benzene and xylene were detected at concentrations of greater than 100,000 ug/l and 16,000 ug/l respectively. These aromatic hydrocarbons would be expected to co-occur with benzene and xylene.

#### 2.4 STRUCTURES CONTAMINANTS

On the basis of use history (see Task 24-Structures Remedial Investigation, Ebasco, 1988s/RIC 88306ROZ), all RMA structures were classified according to their suspected degree of contamination (Table SSA 2.4-1). No structures in the SSA are suspected to be contaminated. Sixteen structures are suspected to be uncontaminated and thirteen structures are suspected to be contaminated but cleanable. Based on visual observation, two structures are suspected to contain asbestos. No structures in the SSA contained process equipment at the time of the Structures Survey in the spring of 1987.

#### 2.5 AIRBORNE CONTAMINANTS

As part of the overall remedial investigation, a one-year baseline air monitoring program was established on-post for use in comparison of air quality prior to, during, and following potential remedial actions. The USATHAMA-approved procedures for collection and analyses of air samples are described in the Task 18 Final Technical Plan (ESE, 1987a/RIC 88203R02). The sample analysis program was based upon recognized reference methods as provided in the Technical Plan. The analysis of total suspended particulates (TSP), particulate matter less than 10 microns (PM-10), and asbestos followed standard EPA and National Institute of Occupational Health & Safety (NIOSH) analytical methods. The reporting limits for metals were determined by the PMO-RMA/USATHAMA reporting limit program and were not lower than the lowest

spiked sample. Complete results of the air monitoring program may be found in the Air Remedial Investigation, Final Report (ESE, 1988c/RIC 88263R01).

### 2.5.1 Analytical Results

There were two air quality sampling locations in the SSA. Station AQ5 was located in the southwest corner of Section 11, and Station AQ6 was located approximately 1,000 ft south of South Plants as shown in Figure SSA 2.5-1. TSP was monitored at both stations; PM10 and metals were monitored at AQ5. Asbestos was monitored at AQ6. Table SSA 2.5-1 summarizes the analytical results from both stations. The occurrence and distribution of contaminants are discussed in the following sections.

#### 2.5.1.1 Distribution of TSP

At AQ5 the analytical geometric average concentration of TSP was 35 micrograms per cubic meter ( $\text{ug}/\text{m}^3$ ), and at AQ6 the average concentration was 33  $\text{ug}/\text{m}^3$ . Both of these levels were below the Federal and state secondary ambient air quality standard of 60  $\text{ug}/\text{m}^3$ .

Thirty-eight individual TSP samples were collected at AQ5 and 41 samples were collected at AQ6. The concentrations of individual 24 hour concentrations at AQ5 ranged from 5.7 to 110  $\text{ug}/\text{m}^3$  and the range at AQ6 was 6.2 to 150  $\text{ug}/\text{m}^3$ . The maximum 24 hour concentrations at both stations were below the Federal and state standard of 150  $\text{ug}/\text{m}^3$  in all but one instance.

The highest annual geometric average TSP concentration at RMA was 47  $\text{ug}/\text{m}^3$ , along the northwest boundary in Section 27. The highest individual 24 hour TSP concentration at RMA was 150  $\text{ug}/\text{m}^3$  at AQ6. TSP levels at AQ5 and AQ6 were comparable to the average values measured at other stations at RMA.

#### 2.5.1.2 Distribution of PM10

PM10 was monitored 23 times at AQ5. The arithmetic average concentration of PM10 was 34  $\text{ug}/\text{m}^3$ , with individual 24 hour concentrations ranging from 13 to 90  $\text{ug}/\text{m}^3$ .



The annual arithmetic average PM10 concentration at AQ5 was  $34 \text{ ug/m}^3$ , with two other sites averaging 18 and  $35 \text{ ug/m}^3$ . The highest individual 24 hour PM10 concentration at RMA was  $94 \text{ ug/m}^3$  at the northwest boundary. The highest value at AQ5 was less than this concentration.

#### 2.5.1.3 Distribution of Asbestos

Airborne asbestos was monitored biweekly for one year at AQ6. None of the 31 samples collected and analyzed contained detectable levels of asbestos above 0.01 fibers per cubic centimeter (f/cc). This observation was also noted at the two other asbestos monitoring stations at RMA.

#### 2.5.1.4 Distribution of Metals

Eight samples were collected at AQ5 and six samples were collected at AQ6 for analyses of ICP metals (cadmium, chromium, copper, lead, and zinc), arsenic, and mercury. Samples were collected during dry, windy events when entrainment of metals would be expected. Arsenic and mercury were not observed above detection limits whereas cadmium, chromium, copper, and lead were observed above detection limits. At AQ5, cadmium levels above detection limits ranged from 0.003 to  $0.007 \text{ ug/m}^3$ , chromium ranged from 0.003 to  $0.008 \text{ ug/m}^3$ , copper ranged from 0.076 to  $0.17 \text{ ug/m}^3$ , lead ranged from 0.016 to  $0.052 \text{ ug/m}^3$ , and one sample contained zinc at  $1.9 \text{ ug/m}^3$ . At AQ6, cadmium levels above detection limits ranged from 0.003 to  $0.004 \text{ ug/m}^3$ , chromium ranged from 0.003 to  $0.12 \text{ ug/m}^3$ , copper ranged from 0.068 to  $0.096 \text{ ug/m}^3$ , lead ranged from 0.01 to  $0.03 \text{ ug/m}^3$ , and one sample contained zinc at  $1.7 \text{ ug/m}^3$ . All of these levels were within the range of results observed at 13 other stations on RMA during 16 sampling events. The highest levels for these elements during any single sampling event were: cadmium  $0.017 \text{ ug/m}^3$ ; chromium  $0.05 \text{ ug/m}^3$ ; copper  $0.91 \text{ ug/m}^3$ ; lead  $0.062 \text{ ug/m}^3$ , and zinc  $10 \text{ ug/m}^3$ .

## 2.6 BIOTA CONTAMINANTS

RMA contaminants have been detected since the early 1950s in the tissues of plants and animals present on RMA. Initial studies were in response to reports of biota mortality and damage. In the 1950s, reports of on-post wildlife mortality and off-post agricultural damage prompted many studies and research projects designed to investigate the causes of the potential

contamination. A number of chemical spills and resultant fish kills in the lakes region at RMA in the 1960s prompted a series of phytotoxicity studies, chemical contamination investigations, and a wildlife census. Subsequently, ecological investigations of broader scope were conducted in support of on-post contamination assessments and restoration planning programs that began in the 1970s. It was during this time, in the mid-1970s, that the first comprehensive baseline surveys were conducted. Many of these studies had an RMA toxicological or ecological emphasis. More recent and ongoing studies, initiated in the early 1980s, have been in support of litigation between the State of Colorado, Shell, the Army, and the EPA. These studies have included chemical analyses, population censuses, phytotoxic response tests, baseline studies, and impact assessments on aquatic organisms, migratory waterfowl, aquatic and terrestrial plants, companion soils where biotic organisms are being studied, terrestrial animals, and micro- and macro-invertebrates. A brief summary of the historical investigations on biota conducted in the SSA is presented in Section 1.3.2.1.

A comprehensive assessment of biota-related contamination, both on-post and off-post, was initiated in 1985. This program was designed to determine what, if any, RMA contaminants remained in the environment and constituted hazards to the regional biota. Contaminant levels in tissues were measured in comparison to levels in off-post controls; however, valuable information was also obtained from samples collected by chance (e.g., raptors found dead on-post and salvaged for analysis). The results of these analyses are discussed in conjunction with information on known effects and potential effects on biota and ecosystems of the SSA in Section 3.0 of this report. A detailed treatment of all aspects of the biota sampling, chemical analysis regime, contaminants considered, and pathways analysis are discussed in the Biota Final Technical plan (ESE, 1988b/RIC 88243R05) and the RI for Biota (ESE, 1989/RIC 89054R01).

#### 2.6.1 Contaminants of Concern

Compounds selected as potential contaminants of concern to biota met the following criteria:

- o Present in the RMA environment above ambient concentrations;
- o Rated at least moderately toxic; and
- o Volume and persistence information indicated that the chemical was present in the environment in sufficient quantity and/or for a long enough period of time to pose a hazard to biota.

Thirty-nine contaminants were selected for evaluation based on this approach (see Section 2.2 of the Biota Assessment Final Technical Plan; ESE, 1988b/RIC 88243R05). Contaminants present in SSA soils or waters that are of concern to biota are shown in Table SSA 2.6-1. Toxicity assessments were prepared for all contaminants of potential concern to biota and are available in the RI for Biota (ESE, 1989/RIC 89054R01). These assessments summarize pertinent information on the nature and extent of existing or potential hazard to wildlife. The data from the assessments were incorporated with information on the concentration and distribution of these contaminants in physical media to provide a quantitative evaluation of RMA contaminant hazards to biota for the SSA and are addressed in Section 3.0 of this document.

Seven contaminants identified as major contaminants of concern were selected for detailed pathways analysis based on their presence in the biosphere (e.g., in physical media within 20 ft of the ground surface), bioconcentration or bioaccumulation potential, and areal extent (more than 5 acres). These contaminants were: aldrin/dieldrin, arsenic, DBPC, endrin/isodrin, and mercury. All seven analytes were found in SSA soils, sediments, and/or waters. Two major contaminants of concern were not analyzed in biological tissues. DBPC, although toxic, does not bioaccumulate significantly, while isodrin, an analog of endrin, is converted to endrin by metabolic processes. Two additional contaminants, DDE and DDT, were analyzed because of their potential implication in adverse biological effects. Both of these analytes behave similarly to the other OCPs and were frequently detected in the SSA. The pathways approach was used to develop criteria levels in soil, water, and sediment for the protection of regional biota, and to evaluate existing levels to determine the nature and extent of contaminant hazards to biota. The results of pathways analysis and bioaccumulation potential, known and potential effects on biota, and the statistical analysis of the contaminants of concern in the Southern Study Area are discussed in Section 3.3.

### 2.6.2 Sampling Completed in the Southern Study Area

The great diversity of wildlife in the SSA yielded an equally diverse sampling effort. Samples for contaminant analysis were taken from eggs and juvenile carcasses of kestrels, mallards, and ring-necked pheasants. Samples of chance included the brains and livers of both a red-tailed hawk and a ferruginous hawk. USFWS samples from Upper Derby Lake were taken in 1985 for northern harrier eggs, blue-winged teals, redheads, and American coots, while a variety of fish, plankton, and macrophyte samples were analyzed from the Lower Lakes. Four mule deer were also taken for muscle and liver tissue analysis from the SSA. A map of terrestrial sample locations is presented in Figure SSA 2.6-1.

### 2.6.3 Contaminant Levels in Species Occurring in the Southern Study Area

Samples were prepared by homogenization and extraction procedures according to standard certified USATHAMA methods. Gas chromatograph/mass spectrometry (GCMS) methods were used to detect pesticides, while atomic absorption spectrometry (AA) methods were used to detect arsenic and mercury. Detection limits (certified reporting limits) for each contaminant are presented in Table SSA 2.6-2.

Contaminant levels in RMA wildlife species found in the SSA are summarized in Tables SSA 2.6-3, SSA 2.6-4, and SSA 2.6-5. The range of concentrations shown on the tables may exceed those actually found in biota collected within the SSA. While some of the wildlife samples were not taken from the study area, most of these species have been located in the SSA or spend some time in the area. Complete tables summarizing the contaminant levels found in all samples taken on RMA may be found in the RI for Biota (ESE, 1989/RIC 89054R01).

#### 2.6.3.1 Raptors

Raptors are a conspicuous component of the terrestrial biota in the SSA. As predators at the top of the food chain, raptors are highly susceptible to the effects of bioaccumulation of contaminants. American kestrels were collected on-post and off-post as part of an avian reproduction study. In the SSA, a single red-tailed hawk and the eggs of a northern harrier were collected. Additionally, a ferruginous hawk found just south of RMA along 56th Avenue was collected and included in the SSA assessment. The carcasses and eggs of

keestrels were analyzed for mercury, aldrin, dieldrin, endrin, DDE, and DDT. The liver and brain were collected from each of the remaining raptors and analyzed for all of the major contaminants of concern.

Liver tissue analyses of the red-tailed hawk revealed contaminant concentrations of 0.76 ug/g DDE, 6.6 ug/g dieldrin, and 0.34 ug/g mercury. Brain tissue of the red-tailed hawk had contaminant concentrations of 9.2 ug/g dieldrin and 0.093 ug/g mercury. The ferruginous hawk found just south of Section 12 adjacent to the SSA was found to contain concentrations of 10 ug/g and 3.4 ug/g dieldrin in brain and liver tissue, respectively. No other analytes were detected. Two eggs collected from a northern harrier nest in the SSA had dieldrin concentrations of 0.30 and 0.68 ug/g. No other analytes were detected.

Dieldrin concentrations in the carcasses of three American kestrels collected in the SSA ranged from below detection limits (BDL) to 1.0 ug/g. No other analytes were detected. Eggs collected from kestrel boxes in the SSA had contaminant concentrations of BDL to 1.3 ug/g dieldrin. No detectable levels of mercury, aldrin, endrin, DDE, or DDT were found.

#### 2.6.3.2 Game Species

Important game species collected from the SSA for contaminant analysis include waterfowl, ring-necked pheasants, and mule deer. The contaminants analyzed for in terrestrial game species were arsenic, mercury, aldrin, dieldrin, endrin, DDE and DDT.

Mallards, redheads, blue-winged teals, and coots were collected by ESE and the USFWS both on-post and from control areas off-post. All other waterfowl species were collected on RMA in the vicinity of the lower lakes.

Mallard eggs collected for analysis in the SSA had from 0.17 to 0.18 ug/g mercury, 3.0 to 4.9 ug/g dieldrin, and 0.61 ug/g to 0.92 ug/g DDE. Of eight adult mallard carcasses analyzed from the SSA, three contained concentrations of dieldrin (from 0.031 ug/g to 4.5 ug/g) and four contained DDE (with 0.10 to 0.36 ug/g). Two juvenile mallard carcasses were retrieved from the SSA, one carcass contained 0.06 ug/g dieldrin, while the other contained 0.52 ug/g

dieldrin and 0.066 ug/g mercury. No other analytes or concentrations were detected in the mallard samples.

Statistical comparisons of analytical results for mallards collected on-post and off-post indicated significant differences in mercury concentrations between juveniles from control and contaminated sites. Significant differences were also found among age groups when contaminated and control sites were pooled. For dieldrin, significant differences were identified between control and contaminated sites for eggs and juveniles and approached significance for adults. Contrasts of pooled contaminated and control sites revealed no differences among age groups for dieldrin. None of the statistical tests for DDE revealed significant differences among treatment groups. Aldrin, endrin, and DDT were not detected in any tissues.

Additional waterfowl samples collected at Upper Derby Lake by the USFWS included blue-winged teals, redheads, and coots. Mercury concentrations in liver tissue ranged from 0.08 ug/g found in a redhead, to 1.8 ug/g found in an American coot. Dieldrin levels in liver tissue ranged from 0.11 ug/g to 0.75 ug/g. DDE, aldrin, and endrin were detected in a single liver sample each, at concentrations of 0.16 ug/g, 0.088 ug/g and 0.074 ug/g, respectively. Muscle tissue analyzed in the three waterfowl species contained levels of mercury, dieldrin and DDE ranging from 0.05 to 0.56 ug/g, 0.062 to 1.8 ug/g, and 0.094 to 0.31 ug/g, respectively.

Juvenile and adult ring-necked pheasant carcasses were collected both on- and off-post and were analyzed for arsenic, mercury, aldrin, dieldrin, DDE, and DDT. Two of five juveniles collected from the SSA contained arsenic, with up to 0.89 ug/g in a sample, while two of five samples contained dieldrin up to 0.21 ug/g. ESE collected two adult pheasant carcasses from the SSA, with both carcasses containing dieldrin at 0.08 ug/g and 2.9 ug/g (the highest concentration of dieldrin found in any adult pheasant sample on RMA). MKE sampled the muscle tissue from three adult pheasant carcasses from the SSA and found 0.063 ug/g dieldrin in one carcass. No other analytes were found in the ring-necked pheasant carcass samples.

Ring-necked pheasant eggs were collected from both on RMA and off-post, and were analyzed for all major contaminants of concern. All five samples taken from the SSA contained dieldrin ranging from 0.069 ug/g to 5.4 ug/g. No other analytes were detected.

Four mule deer were collected from the SSA and two mule deer were collected from off-post control areas. Liver and muscle tissues were analyzed for arsenic, mercury, aldrin, dieldrin, and endrin. No contaminants were detected in either tissue from control deer, and no contaminants were found in muscle of liver tissue of deer collected from the SSA.

#### 2.6.3.3 Aquatic Samples

Specific contaminant levels for fish and plankton samples are listed in Table SSA 2.6-4. All of the samples in the above table were taken from the SSA. Aquatic organisms collected from the SSA and off-post controls (McKay Reservoir, northern Adams County) included plankton, aquatic macrophytes, and several species of fish, including bass, bluegill, northern pike, and black bullhead. Samples collected in 1986 were analyzed for mercury and dieldrin, while mercury, dieldrin, aldrin, and DDE were analyzed in samples collected in 1988. Specific contaminant levels for fish and plankton samples are listed in Table SSA 2.6-5.

Plankton samples were composites gathered from Lake Mary, Lake Ladora and Lower Derby Lake. Arsenic was detected in plankton collected from Lake Mary. Similarly, Lake Mary aquatic macrophytes contained arsenic, while those from Lake Ladora did not. Historically, sodium arsenite was used in Lake Mary to treat vegetation overgrowth; therefore, the presence of arsenic in aquatic samples may represent residual effects of these treatments.

Various tissue samples from bass and northern pike contained levels of mercury in excess of the Food and Drug Administration (FDA) guideline of 0.3 ug/g. Bluegill and black bullhead also contained mercury. Lower Derby Lake and Lake Ladora samples had the highest mercury levels, which tended to be most concentrated in the fillet tissues. Aldrin was detected in various tissues of bass collected from Lower Derby Lake at concentrations up to 0.053 ug/g.

Dieldrin concentrations in the tissues of all fish were found not to exceed the FDA limit of 1.0 ug/g. Levels of dieldrin appeared highest in bass collected from Lower Derby Lake in 1988 (up to 0.86 ug/g). DDE was detected at concentrations up to 0.84 ug/g in bass and black bullhead from Lower Derby Lake. Neither endrin or DDT were detected in any fish or plankton collected.

No significant statistical differences were observed between species and between lakes for 1986 analytes. Significant differences were approached in the preliminary Kruskal-Wallis analysis of variance that compared bass and bluegill among RMA lakes. Significant statistical differences for dieldrin contamination were approached only when samples from all lakes were pooled together.

Lower Derby Lake and a control lake in western Adams County, McKay Reservoir were the only lakes sampled in 1988, and analyses were therefore restricted to these data sets. No significant differences were observed between tissues, lakes, species, and year for all analytes. Significant differences were observed, however, between Lower Derby Lake and McKay Reservoir regardless of tissue type for mercury, dieldrin, and DDE.

Further analysis of the 1988 data showed that each of four analytes (dieldrin, aldrin, DDE, and mercury) exhibited highly significant differences between Lower Derby Lake and McKay Reservoir for bass, despite small sample sizes, but not for bluegill. However, it is recognized that use of a single control lake and a single contaminated lake in statistical analyses, restricts interpretation of significance or nonsignificance to a qualitative level due to the physical and hydrologic differences between the two lakes.



### 3.0 CONTAMINATION ASSESSMENT

In Section 1.0 of this study area report, the history, geology, and hydrology of the Southern Study Area (SSA) were presented. Section 2.0 presented the analytical results from previous investigations and current Remedial Investigation (RI) programs for soil (including sediments), surface water, and groundwater. Section 3.0 presents the integration of all background and chemical information in previous sections and provides an overall environmental contamination assessment of the SSA.

Contaminants are evaluated in Subsection 3.1, Conditions of Contamination, to determine those that will be addressed in the greatest detail. The entire list of analytes detected in the SSA, as discussed in Section 2.0, has been evaluated to focus on specific analytes or groups of analytes that were detected at the highest concentrations or in the greatest frequency. Chemical behavior of these analytes also has been considered as it relates to migratory potential and environmental fate.

Areas where contaminants were detected have been examined in Subsection 3.2, Source Areas, to evaluate which areas contain the greatest frequency of contaminants, and which areas could be sources for future contaminant migration. The discussion explains which areas in the SSA can be considered source areas based upon contaminant occurrence, media characteristics affecting contaminant transport, historical information, and the propensity for contaminants to migrate.

The analytes and analyte groups screened in Subsection 3.1 are discussed separately in Subsection 3.3, Migration Pathways, in terms of their migratory potential and potential receptors. Several migration mechanisms including leaching, surface and groundwater movement, volatilization, and bioaccumulation are examined to assess contaminant pathways present in each of the major source areas. Correlations regarding contaminant movement are drawn from historical data, chemical properties of the contaminants, physical and chemical properties of soil and water, and distribution of the contaminants within various media. With this information, an assessment is presented discussing the potential for further contaminant migration from the source

areas into other areas or into other media. Finally, for each analyte or analyte group, an evaluation is made regarding which receptor(s) are likely to be affected. Both biological (living animals or vegetation) and physical (soils, geology, and groundwater) receptors are considered.

Subsections 3.4 through 3.7 address Volume of Potentially Contaminated Soil, Mass Flow Rate of Potentially Contaminated Groundwater, Interim Response Actions, and Conclusions, respectively.

### 3.1 ENVIRONMENTAL PROPERTIES OF POTENTIAL CONTAMINATION

In this section the chemical and physical behavior of analytes detected in soils, sediments, water, air, and biota are presented in this section, followed by a general discussion regarding the physical and chemical parameters of note that govern analyte behavior in the SSA.

Chemical analyses of samples collected from the SSA indicated that compounds of concern were detected above their Certified Reporting Limits (CRL) in various media. Analytes that were detected in the SSA media during the RI are summarized in Table SSA 3.1-1.

#### 3.1.1 Characteristics of Contaminant Behavior

There are numerous factors that influence the transport of contaminants through the unsaturated zone to the water table, and their subsequent transport in groundwater and surface water. The efficiency of contaminant transport mechanisms and the ultimate fate of contaminants are influenced by the physical and chemical properties of specific contaminants as well as characteristics of the environment. Contaminant properties that influence behavior in soil and water environments include physical state, density, aqueous solubility, vapor pressure, Henry's law constant, and the soil-water partition coefficient. These properties for analytes detected in the SSA are summarized in Table SSA 3.1-2. While the following discussion on chemical behavior presents data generally obtained under laboratory conditions, it is important that these values are used as guides to identify potential trends occurring under field conditions similar to those existing in the SSA.

The relative magnitude of the organic carbon partition coefficient ( $K_{oc}$ ), Henry's law constant ( $K_h$ ), and solubility of each analyte (Table SSA 3.1-3) is directly proportional to the affinity of that compound for the solid, gas and liquid phases, respectively. For example, high organic carbon partition coefficients ( $K_{oc}$ ) and soil-water partition coefficients ( $K_d$ ), which are indicative of an analyte's affinity for the solid phase, can be correlated to low mobility in groundwater. High  $K_{oc}$  and  $K_d$  values also suggest the potential for wind transport of these compounds if they exist in susceptible surface soils. Conversely, high solubility of an analyte indicates that it is readily transported in surface or groundwater. Its retardation rates are expected to be limited, and its potential for leaching and impacts to groundwater are more likely. Thus, in a relative sense, low  $K_{oc}$  and  $K_d$  values and high solubilities can be inferred to indicate greater mobilities in groundwater. A full list of contaminant properties are discussed in greater detail below, emphasizing their impacts on mobility in groundwater.

$K_{oc}$ ,  $K_h$ , and Bioconcentration Factors (BCFs) for some target analytes were available from chemistry and toxicity profiles compiled by the U.S. EPA Office of Emergency and Remedial Response (OERR) and Waste Program Enforcement (OWPE), as well as the U.S. Army Biomedical Research and Development Laboratory (USABRDL). Where empirical data were not available, predictive equations were used to estimate these parameters where applicable. If multiple sources were available, geometric means from several calculations were used to produce Maximum Likelihood Estimators (MLEs) for individual analytes. References utilized for the purpose of calculating MLEs may be found in Appendix D.

The physical state of all compounds detected in the SSA, as presented in Table SSA 3.1-2, is based on the stable phase of the analyte (solid, liquid, gas) at ambient temperature (20 degrees C) and pressure (1 atmosphere). Chemicals released to the environment in the solid form, such as DDT, do not readily move through the soil matrix, whereas contaminants in the liquid form, such as trichloroethylene, typically flow into subsurface soil and aquifers more readily. Some contaminants found in the SSA, such as aldrin, endrin, and dieldrin, typically occur in solid form. These compounds were usually

dissolved in an organic solvent during manufacture or use, which may promote transport through the soil matrix.

Density is defined as the ratio of mass to unit volume. Specific gravity, a related parameter, is the ratio of the mass of given volume of a compound to that of an equal volume of water. In sufficient quantities, nonaqueous phase liquid contaminants with a density less than water will float on the water table surface. SSA analytes that are less dense than water in their pure forms include toluene and dicyclopentadiene. Conversely, dense nonaqueous phase liquid contaminants heavier than water will migrate downward in the aquifer until an impermeable barrier is encountered. SSA analytes that are heavier than water in their pure form include chloroform trichloroethylene, and tetrachloroethylene.

Aqueous solubility for each compound detected in the SSA represents the maximum concentration that will dissolve in a unit volume of water under specified conditions. If concentrations exceed aqueous solubility, the compound exists both in solution and as a separate solid, liquid, or gas phase. Variables in surface water and groundwater that affect individual analyte solubility include pH, water hardness, cation and anion concentration, naturally occurring organic substances (e.g., humic and fulvic acids), and the presence of other organic contaminants. Although these variable are thought to affect the solubility of organic contaminants in aqueous systems, their precise impact on contaminant mobility is difficult to assess. The current state of knowledge precludes a general discussion of these effects. Where variations in bulk solution composition appear to affect contaminant mobility, these variations are discussed in Section 3.3 Migration Pathways. Tables SSA 1.5-1 through 1.5-4 present the results of water quality measurements in the SSA lakes. Highly soluble compounds are generally subject to wider distribution than contaminants of limited solubility.

Vapor pressure is the pressure at which a compound and its vapor are in equilibrium at a given temperature. Hence, the potential for a contaminant to volatilize from soil can be predicted. Vapors may diffuse into the atmosphere, be retained in pore spaces of unsaturated soil, or collect in subsurface structures such as sewers or basements.

For a vapor-liquid equilibrium system, Henry's law constant ( $K_h$ ) represents the ratio of a compound's concentration in the vapor phase to its concentration in the aqueous phase.  $K_h$  provides a more reliable measure of the relative volatilization from water than simple vapor pressure and can be used to approximate environmental fate since it can be related to the degree of volatilization and persistence in surface water. The effects of volatilization are most pronounced in flowing surface water due to contact with the atmosphere. Although this mechanism is also active in the vadose and saturated zones, the restricted transfer of gases in the vadose zone limits the impact of volatilization. In coarse-grained, surface to shallow soils, volatilization of compounds with high Henry's law constants may result in transfer to the vapor phase within pore spaces, and subsequent transport to the atmosphere by a variety of mechanisms. Deeper in the vadose zone or within fine-grained sediments, transfer of organic vapors results in the detection of volatile organic compounds which exist primarily within fine-grained horizons and near the capillary fringe.

In two-phase systems (liquid-liquid or solid-liquid), chemical species are usually detected at higher concentrations in one of the two phases. The partition coefficient for SSA compounds (Table SSA 3.1-2) constitutes the equilibrium concentration ratio for a dissolved substance in a two-phase system. The octanol-water partition coefficient ( $K_{ow}$ ) is defined as the equilibrium concentration ratio of a dissolved substance in a two-phase system of n-octanol and water. High  $K_{ow}$  values can be used to predict a chemical's tendency to adsorb on clays or soil organic matter, or to be subject to biological uptake and lipophilic storage.

While  $K_{ow}$  is reproducible in the laboratory, it is not directly applicable to partitioning of organic contaminants between soil or sediment and a co-existing water phase. Empirical equations have been derived relating  $K_{ow}$  to the soil-water coefficient ( $K_d$ ) and the soil organic carbon content ( $f_{oc}$ ) through an intermediate parameter, the organic carbon partition coefficient ( $K_{oc}$ ), which is also tabulated in Table SSA 3.1-2. As with  $K_{ow}$ , compounds with high  $K_{oc}$  or  $K_d$  values are preferentially partitioned onto the solid phase. As a result, contaminant mobilities in groundwater are inversely proportional to  $K_d$  and  $K_{oc}$ .

In sediments, the percentage of organic carbon may approach or exceed the lower level of applicability of the  $K_{oc}-K_d$  relationship, which is approximately 0.01 percent  $f_{oc}$ . Lake sediments in the SSA have a minimum organic carbon content of 0.1 percent. Therefore, the  $K_{oc}-K_d$  relationship is applicable in lake sediments. In sediments with low organic carbon content, however, sorption becomes increasingly dominated by clay minerals in the sediments, and may be related to the surface area, grain size, and percentage of silt and clay within the sediment. In most cases, sorption of organic compounds will generally increase with increasing silt and clay content.

The high variability of both field and literature partitioning data suggests that these data are more suitable for describing the relative behavior for a suite of contaminants in a similar environment, rather than absolute mobilities. Hence, contaminants detected in the SSA are interpreted as having high, moderate, and low affinities for soil and aquifer solids (Table SSA 3.1-3). SSA contaminant mobilities in the aqueous phase are inversely proportional to the partition coefficient, and directly proportional to mobility.

The bioconcentration factors listed in Table SSA 3.1-2 represent the degree to which a contaminant may accumulate in aquatic organisms, and is defined as the ratio of contaminant concentration in an organism to the corresponding concentration in water. Contaminant accumulation in aquatic organisms presents the potential for significant ecological hazard. Concentrations which appear safe based on aquatic bioassay criteria for acute or even chronic exposure can accumulate to levels that may be harmful to consumers of those organisms. The accumulation of agricultural pesticide residues in fish, for example, has led to decreasing reproductive success in certain predatory birds that feed on fish.

Finally, transformation and degradation processes, discussed in Section 3.3, determine whether a chemical will persist in the environment. Key processes include both chemical and biological mechanisms, such as hydrolysis, photolysis, oxidation-reduction, and biotransformation. Specific rates at

which these processes occur are dependent on individual chemical and environmental characteristics. In general, surface processes occur at faster rates than subsurface processes. Therefore, a chemical that is buried will generally degrade at a slower rate than the same chemical exposed at the soil surface.

Several chemical reaction mechanisms potentially contribute to the overall process of chemical transformation. Hydrolysis, photolysis, and oxidation reduction reactions are the primary components of chemical transformation in soils, although other reactions may be significant for individual compounds of interest. USEPA (1979) is a source of information regarding potential transformations which affect priority pollutants in aqueous systems. A brief description of each major class of reactions is provided below.

During hydrolysis, an organic compound reacts with water, resulting in the introduction of a hydroxyl group into the molecule and subsequent elimination of another functional group, such as a halogen. Hydrolysis may be catalyzed by acid ( $H^+$ ), base ( $OH^-$ ), or metal ( $M^+$ ) ions; thus, the rate of hydrolysis is pH and metal-ion-concentration dependent. Surface effects may also influence the rate of hydrolysis. Hydrolysis of some pesticide derivatives is more rapid in the presence of humic materials.

Photochemical processes include both direct photolysis and sensitized photolysis. In direct photolysis the compound absorbs solar radiation and is transformed, while in sensitized photolysis, the energy which transforms the compound is derived from another species in solution. Photolysis reactions may occur in either air, near-surface soils, or surface water.

Oxidation-reduction (redox) reactions involving both inorganic and organic compounds are important in soil and water environments. Inorganic chemists define oxidation as the loss of electrons and increase in oxidation number, while reduction is the gain of electrons and decrease in oxidation number. Organic oxidation reactions generally involve a gain in oxygen and loss of hydrogen, while the reverse is frequently true for organic reduction. Oxidation often requires the presence of  $O_2$ , but the reaction usually

involves free radicals, especially OH, RO<sub>2</sub>, RO, and singlet oxygen as the oxidant (where R = carbon chain or ring). Redox reactions are often biologically mediated, but can also occur in abiotic systems. Chemical structures most susceptible to oxidation include phenols, aromatic amines, and dienes. Unsaturated alkyl compounds such as alkenes, halogenated alkenes, alcohols, ester, and ketones are not readily oxidizable in the groundwater environment (Cherry, et al., 1984).

Reductive dehalogenation involves the removal of a halogen atom via an oxidation reduction reaction. This reaction is most likely to occur in low-redox state groundwaters where oxygen has been depleted. This reaction requires mediators, such as Fe<sup>+3</sup> or naturally occurring biological products, to accept electrons generated by oxidation of reduced organics, and to transfer these electrons to the halogenated organic compound to bring about dehalogenation (Mackay, et al., 1984).

Biotransformation occurs as a result of the metabolic activity of microorganisms through the action of enzymes which catalyze chemical reactions. Rates of biotransformation are dependent on microbial tolerance to specific contaminant compounds and the availability of groups of compounds, such as oxygen and nitrate, as nutrient sources. Therefore, rates of biodegradation are dependent upon microbial population and environment as well as the physical/chemical properties of the compound. Although only limited information is available on rates of biodegradation, historical data and field studies may be helpful in evaluating the importance of biodegradation.

Although the general effects of these processes are described above, they are discussed where applicable for analyte groups in Section 3.3 Migration Pathways.

### 3.1.2 Overview of Analyte Groups in the SSA

As discussed in Section 2.0, the contaminants detected in soil and sediments in the SSA were subdivided into several analyte groups, namely, volatile halogenated organics (VHO), volatile hydrocarbons (VHC), volatile aromatic organics (VAO), semivolatile halogenated organics (SHO), organochlorine



pesticides (OCP), and ICP metals. The individual analytes considered include dibromochloropropane (DBCP), arsenic, and mercury. Likewise, the contaminants detected in surface and groundwater were subdivided into several analyte and individual contaminant groups, and include VHOs, VHCs, VAOs, DBCP, OCPs, SHO, arsenic, mercury, ICP metals, plus organosulfur compounds (OSC) and organophosphorous compounds (OPH). The contamination assessment focuses on the more significant contaminants in the SSA. However, the assessment does not preclude discussion of less prevalent or mobile analytes.

In an effort to determine which of the analytes detected in the SSA merit relative degrees of concern, from a risk assessment perspective, they have been evaluated to assess those that meet one or more of the following criteria:

- o Analyte was detected at an elevated concentration or frequency in soils, sediments, surface water, or groundwater;
- o Analyte was detected in more than one medium (soil, water, biota);
- o Analyte was historically produced, stored, used, or disposed in the SSA;
- o Distribution of the analyte is widespread in the SSA, or;
- o Analyte has a high persistence or mobility in the environment.

The foundations of the first four criteria are based on data presented in Sections 1.0 and 2.0 of this report. The remaining criterion is based upon the chemical and physical properties of the contaminant which affect its transport behavior through various environmental media. Table SSA 3.1-2 presents the chemical properties for analytes detected in all media in the SSA. Table SSA 3.1-3 lists SSA Organic Target Analytes and provides relative ratings for partition coefficients and solubility. The wide range of these parameters reported in scientific literature, coupled with the nonhomogeneous environmental conditions in the SSA, invalidates the use of a more quantitative table. Instead, a relative ranking system is utilized here for the purpose of relating transport potential in groundwater (as a function of  $K_{oc}$ ,  $K_h$ , and solubility) for the different organic analytes in the SSA. Inorganic contaminants are not included in this table because of their wide

variance in species behavior and response to changes in local environmental conditions such as pH, Eh, and sediment characteristics. The inorganic compounds are discussed in greater detail in the text below to facilitate an understanding of their mobility in the SSA. The contaminants that met the aforementioned screening criteria to the greatest degree are:

- o Volatile halogenated organics (VHOs)
- o Volatile aromatic organics (VAOs)
- o Volatile hydrocarbons (VHCs)
- o Dibromochloropropane (DBCP)
- o Semivolatile halogenated organics (SHOs)
- o Organochlorine pesticides (OCPs)
- o Arsenic
- o Mercury
- o ICP Metals

The following discussion of analyte groups relies on chemical parameters outlined in Table SSA 3.1-2 and 3.1-3. The results of chemical behavior and migration potential are discussed in detail in Section 3.3 Migration Pathways. VHO compounds are chlorinated solvents that readily mobilize from shallow, sandy soils by the mechanisms of volatilization and leaching. These compounds were readily used at RMA and are commonly found in industrial settings. They are not unique to RMA activities. Several analytes in this group were detected or reported in the SSA, most notably in the area of the lakes and ditches. Their presence at distances of over one mile from their presumed points of origin or disposal underscores their mobile nature. Abiotic and biotic transformations of these compounds to less halogenated forms may alter the exposure risk of these analytes to biota.

VAO compounds in the SSA include analytes derived from petroleum products, particularly hydrocarbon fuels such as gasoline. These compounds are also found in industrial solvents. Many of the VAOs found in the groundwater within the SSA boundaries were used in South Plants, though they are not unique to RMA. VAOs, particularly benzene, have been detected in SSA groundwater flowing away from the South Plants Study Area (SPSA). Although VAOs have been sporadically detected in soils and sediments, evidence of surface water transport in SSA ditches has been noted.

VHC compounds, like VAOs and VHOs, were detected in surface waters and groundwater near the SPSA, north of the lakes. Many of the VHCs, such as dicyclopentadiene, were used as feedstock for the production of pesticides in the South Plants manufacturing complex. The distribution of the VHCs in the SSA is closely attributable to RMA activities.

DBCP is a nematocide which was manufactured by Shell Oil Company and its affiliate Shell Chemical Company (collectively referred to as Shell) in the SPSA. Its presence is found predominantly in the lakes, although it has been noted in buried lake sediments and other scattered locations. Like the OCPs, DBCP is persistent in the environment, but is present only at fairly low concentrations and does not readily bioaccumulate.

SHO compounds, specifically, hexachlorocyclopentadiene were detected in sediments upgradient of the Sections 1 and 2 ditch systems. This chemical was a processed intermediate during aldrin, dieldrin and endrin manufacture from 1952 to 1974 (RMA Chemical Index, Ebasco, 1988). Several spills of this compound were reported from 1949 through 1964. SHOs low in solubility and exhibit a strong affinity for soil organic carbon and mineral surfaces. As an analytical group similar in nature to OCPs, bioaccumulation and biomagnification potential is significant.

OCPs were detected at elevated concentrations, and were variably distributed within several media in the SSA. These pesticides were manufactured on RMA by CF & I, Julius Hyman and Company and Shell. Surface water has largely contributed to the dispersal of these compounds into the SSA from the SPSA, where they were originally manufactured. Dispersion of contaminants has occurred via the process water ditch system, groundwater transport, and eolian processes. The mobility of OCPs is relatively low suggesting that their propensity to migrate to other sources is enhanced by active, high energy transport pathways such as surface water runoff. In addition, historical evidence dating back to 1952 suggests that bioaccumulation of these compounds (particularly aldrin, dieldrin, dichlorodiphenylethane (DDE) and dichlorodiphenyltrichloroethane (DDT)) in SSA biota has been substantial.

Arsenic and mercury were detected in soils and sediments in the lakes and ponds of the SSA and in the drainage systems exiting from South Plants. Arsenic, though naturally ubiquitous, was a component of the raw material and byproduct of Lewisite manufacture and demilitarization. This element's distribution is not unique to RMA activities. Mercury was used at RMA as a catalyst to speed chemical reactions. Several spills of this metal occurred in South Plants from 1948 to 1975. These metals were also detected in waters throughout the SSA, including surface water sampling locations in on-post ditches along the extreme southern border of RMA. Elevated concentrations of these metals may be an indication that they are mobile under favorable chemical and physical conditions. Mercury has been documented at concentrations well above Food and Drug Administration (FDA) guidelines in fish in the SSA. Conditions affecting the mobility and persistence of these two metals are discussed in detail in Section 3.3, Migration Pathways.

ICP metals are ubiquitous in nature and were generally detected throughout the SSA at concentrations within the indicator range established for soils. However, those areas and media where ICP metals were detected above indicator ranges (in both soils and water of SSA lakes and ditches, in particular) will be discussed in detail.

The ICP metals, cadmium, copper, lead, and zinc, behave similarly in the environment. Although solubilities of these metals vary widely under commonly encountered environmental conditions, their aqueous mobility is limited by sorption to mineral and organic solids. As a result, they are generally associated with soil or sediment, rather than the surface water or groundwater phase. Leaching of cadmium, copper, lead, or zinc from soils is difficult due to the abundance of sorptive solids, particularly of pH 7 or greater. Partitioning measurements indicate an increasing affinity for the solid phase in the following order: cadmium < zinc < copper < lead (Dragun, 1988).

The mobility of OSC's are enhanced by the relatively high volatilities, low to moderate solubilities and low to moderate affinities for soil organic matter. OSC compounds have also been derived from the manufacture of herbicides and demilitarization of mustard-agents in the South Plants area, and are generally

associated with RMA activities. This is evidenced by the detection of several herbicide- and mustard-related OSCs in the groundwater near the SSA boundary within the SPSA. However, soils and sediment analyses did not note the presence of these compounds, nor were they detected in SSA biota. The relative scarcity of detections in several environmental media limits their discussion and interpretation.

Like the OSCs, OPH compounds were scarcely detected in SSA environmental media. Where detected their chemical behavior indicates a high degree of mobility in the environment. Diisopropylmethyl phosphonate is known to be a byproduct of the manufacture of the nerve agent GB (or Sarin) in the North Plants complex. Therefore, its distribution, though only occasional, is associated with RMA activities, and exposure potential to biota is possible.

### 3.2 SOURCE AREAS

To assist in presentation of the contamination assessment, the SSA was divided into five areas. These areas were established based upon historic use, location, and hydrologic relationships, and are:

- o SSA 1: Lakes and Ponds
- o SSA 2: Ditches and Overflow Basins
- o SSA 3: Buried Lake Sediments
- o SSA 4: Excavations, Disposal Sites, and Surface Disturbances
- o SSA 5: Balance of Areas Investigated

The results of the RI were used to redesignate sites in these areas. Some of the original RMACCPMT sites have been dropped and the boundaries of others have been revised. New sites have also been added. The revised boundaries and boundaries for new sites are based on RI analytical results, historical information, and distribution mechanisms. The redesignated sites are shown on Figure SSA 3.2-1. Table SSA 3.2-1 outlines these areas in terms of their

RMACCPMT site designations, revised site designation, site name, and site description.

It is important to define and clarify the context in which the word "source" will be used in this report. There were no areas in the SSA where potential contaminants were actually produced. There were, however, areas designed as disposal sites where contaminants were placed, such as the buried lake sediments and the trash dump. In addition, there are areas that continue to function as physical pathways for dispersion of contaminants, such as the ditches. Finally, there are areas such as the lakes, which receive contaminants discharged from South Plants via the ditch systems, and where the contaminants have ultimately settled into the bottom sediments. None of the designated contamination sites in the SSA are points of origin or primary sources of contaminants. Rather, they are sites of potential contamination which presently function as either repositories or as secondary sources of contaminants that in turn have the potential to migrate to other geographic areas or environmental media.

### 3.2.1 Site Categorization

Site categorization is based upon the spatial distribution of key contaminants in soils and water and the source of the contaminants. The three categories are as follows:

- 1) Category 1 - Analytes were present only in surface soils or at the exact location of waste disposal, but were not detected between the surface and the bottom of the disposed waste and the water table;
- 2) Category 2 - Analytes were present in unsaturated (vadose) zone soils below the disposal site, but these soils do not appear to be contributing contaminants to the water table; and
- 3) Category 3 - Analytes were present throughout the soil column in saturated and unsaturated (vadose) zone soils and in the groundwater, suggesting an apparent relationship between soil contaminants and those found in the water table.

The site categorization framework was initially developed to assist the Feasibility Study in developing appropriate remedial responses at the site(s) of contamination. It should be noted that source area categorization is based on the occurrence of the one analyte or analyte group exhibiting the greatest vertical distribution. Subsequently, the worst-case example is utilized for ranking each source area. For example, mercury may only be found at the surface of a source area, whereas trichloroethylene is detected throughout the vadose zone as well as in groundwater in the same source area. Hence, the source would be designated as Category 3 based on the trichloroethylene distribution.

Table SSA 3.2-2 presents the preliminary categories assigned to each of the five SSA Sites. This table classifies these analytes by the nature of their distribution in each of the sites.

#### 3.2.2 SSA 1: Lakes and Ponds

Both the water and sediments from the lakes and ponds in SSA 1 warrant consideration as potential secondary sources of contamination. The secondary source areas are Eastern Upper Derby Lake (SSA 1a), Upper Derby Lake (SSA 1b), Lower Derby Lake (SSA 1c), Rod and Gun Club Pond (SSA 1d), Lake Ladora (SSA 1e), and Lake Mary (SSA 1f). Historical investigations of the major lakes (Upper and Lower Derby Lakes and Lake Ladora) and lesser water bodies clearly present a pattern of widespread distribution of several analytes. The biota RI program corroborates historical conclusions that found these locations to be significant sources of biota exposure.

Historically, several of the lakes were used as part of the South Plants cooling water system, through which water was distributed and returned in a loop to the South Plants manufacturing complex. During the early 1940s, liquid wastes from the IOB complex at the eastern end of South Plants were discharged to a ditch connecting with the process water return ditch to Upper Derby Lake (Whitman, et al., 1943; Whitman, et al., 1954; Khaus, 1985, Messex, 1985). No additional records indicate that waste from the complex was disposed directly into the lakes region, suggesting that the analyte distribution is an indirect result of either: (1) recirculated process

cooling water potentially contaminated by defective equipment; (2) contaminants migrating from South Plants area to Lower Derby Lake and the inlet channel to Lake Ladora; (3) cleaning materials in the salvage yard that were laden with residues containing aldrin and dieldrin; (4) accidental releases into the process water return lines; or (5) surface water run-off from buildings and paved areas in the South Plants Study Area.

Hydrologically, all the lakes in the SSA tend to be connected, either by year-round or intermittent surface water flow or by groundwater surface water interactions. The hydrologic interaction between these water bodies has enhanced the spread of potential contaminants through various migration pathways.

Eastern Upper Derby Lake sediments contain OCPs. Sporadic detections of VHOs and arsenic also occurred in the sediments. Upper Derby Lake Sediments contain VHOs, OCPs, SHOs, arsenic, mercury, and ICP metals. Lower Derby Lake sediments contain OCPs, DBCP, mercury, and ICP metals. Lake Ladora sediments contain VHOs, VHCs, OCPs, DBCP, arsenic, mercury, and ICP metals. Lake Mary sediments contain OCPs and arsenic. The Rod and Gun Club Pond contains VHOs and OCPs.

### 3.2.3 SSA 2: Ditches and Overflow Basins

All of the ditches and overflow basins (SSA 2) are potential sources for further contamination. The three source areas are Section 1 ditches (SSA 2a), Section 2 ditches (SSA 2b) and associated ditch in the Northwest corner of Section 2, west of Lake Mary (SSA 2c). Contaminant occurrence in the ditches and overflow basins may have resulted from, but are not restricted to, the following: (1) ditches were used as part of the South Plants cooling water and overflow systems to route water from the eastern South Plants area to Lakes Derby and Ladora; (2) storm water run-off was and is currently flowing via sewers and culverts from the SPSA into the ditches; and; (3) waste and spills from the chlorine plant and other buildings in the South Plants area were intermittently routed through the ditch systems and Sand Creek Lateral. The northern portion of the Sand Creek Lateral in Section 2 was and is currently receiving run-off discharge from South Plants. The ditch and



overflow basin west of Lake Mary often received overflow from Lake Ladora and Lake Mary. The sediments from Section 1 ditches contain VAOs, OCPs, mercury, and ICP metals. The Section 2 ditches contain SHOs, OCPs, mercury, and ICP metals. The sediments from the overflow basin contain VHOs, OCPs, arsenic, and mercury.

#### 3.2.4 SSA 3: Buried Lake Sediments

The two buried sediment areas (SSA 3) are considered potential secondary source areas due to the contaminants entrained within them. The two source areas are Section 11 sediments (SSA 3a) and Section 12 sediments (SSA 3b). Historical records and contamination investigations clearly link the two buried sediment areas to sediments excavated from Lake Ladora and Upper and Lower Derby Lakes. Due to the apparent stability of the soil and clay materials encasing these disposal areas, migration of contaminants beyond the boundaries of the sources is marginal. The buried lake sediments in Section 12 contain DBCP, SHOs, OCPs, and mercury. Buried lake sediments in Section 11 contain mercury and ICP metals.

#### 3.2.5 SSA 4: Excavations, Disposal Sites and Surface Disturbances

In SSA 4, only the trash dump (SSA 4a) warrants consideration as a potential secondary source of soil contamination. Based upon the results of the RI program and historical information, other excavations, disposal sites, or surface disturbances are considered nonsource areas and will not be discussed further. The trash dump occasionally received trash and debris, including large concrete blocks, pipes, and steel beams. Organochlorine pesticides detected in this area may have resulted from surface water run-off transporting these compounds from contaminated debris or fill material in South Plants. Sediments from this area also contain VHOs, VHCs, SHOs, and OCPs.

#### 3.2.6 SSA 5: Balance of Areas Investigated

SSA 5, portions of Sections 1, 11 and 12, warrant consideration as potential secondary sources of contamination because of the presence of VHOs, VAOs, DBCP, SHOs, OCPs, arsenic, mercury, and ICP metals in surface water, groundwater or ditch sediments. Specific areas include upland soils adjacent

to the trash dump (Section 1), scattered upland areas near the target range and Rod and Gun Club Pond (Section 12), and the areas within and associated with the Havana Ponds. The balance of Sections 1, 7, 11 and 12 investigated under the RI program were not found to contain contaminants of concern and will not be discussed as sources.

### 3.3 MIGRATION PATHWAYS

Contaminant migration from sources identified in Subsection 3.2 is governed by several factors, including: the chemical and physical properties of the source and surrounding media; the chemical properties of the contaminants in these media (as discussed in Section 3.1); and the chemical and physical processes that affect the migration potential of contaminants. The interaction of these properties and processes define the pathways for contaminant migration and establish those potential receptors affected by the migration of these contaminants. This section discusses the migratory potential of each analyte group detected in SSA media and potential receptors of these analytes. Relative mobilities of each analyte or analyte group in air, soil, and water are briefly discussed, and general observations regarding their transformation processes, biodegradation, and bioconcentration are provided. These discussions are based primarily on chemical property data presented in reports by USEPA (1982), Moore and Ramamoorthy (1984a; 1984b), and Dragun (1988). Descriptions of theoretical analyte behavior have been compared to observed distribution, hydrogeology, and site history to determine significant transport mechanisms and migration pathways. Potential human and ecological receptors have also been identified on the basis of this migration pathways analysis.

Table SSA 3.3-1 presents a list of all contaminants detected in the five primary media studied in the SSA during the RI. This summary is useful in the migratory potential of each analyte and the interaction between each of the media. It also serves as a basis for understanding the potential environmental fate of each analyte in the SSA. Complete lists of the analyses performed for soils and sediments, surface water and groundwater (and respective CRLs) may be found in Appendix SSA-A. All analyses conducted for air and biota are described in Sections 2.5 and 2.6, respectively.

This section also discusses the presence of contaminants in surface water and groundwater that are not directly linked to sources defined earlier in this section. In some cases, the source of water contamination has been determined to originate from undefined off-post locations to the south of RMA. Significant concentrations of contaminants, not included in the contaminant list (Section 3.1), were also detected in surface water and groundwater samples where there was no apparent on-post soil or sediment source. These anomalies also are addressed.

The chemical properties of contaminants have been summarized in Table SSA 3.1-1. These chemical properties are part of what controls fate and transport for each of the contaminants found in the SSA. In a similar fashion, several physical and chemical parameters of soils influence the likelihood of contaminant transport from surface soils to the unsaturated vadose zone and underlying groundwater. These parameters include texture, structure, bulk density and hydraulic conductivity, soil reaction (pH), organic carbon content, ion exchange capacity, electrical conductance, and oxidation-reduction (redox) potential. These soil characteristics are summarized in Section 1.4.1 and are discussed in this section relative to each of the analyte groups presented.

In the course of examining historical information, the analytical results from the RI, physico-chemical properties of host media, chemical behavior of potential contaminants, and significant migration mechanisms, the following migration pathways were considered in the SSA:

- o Infiltration through the vadose zone
- o Surface water transport
- o Eolian transport
- o Groundwater transport
- o Soil vapor transport
- o Bioaccumulation
- o Anthropogenic transport

There are several primary and secondary processes or mechanisms that appear to control migration pathways from medium to medium or from source to source in the SSA. These processes are leaching, sorption, surface water movement, volatilization, advection, dispersion, biodegradation and bioaccumulation.

The discussion of migration pathways addresses these mechanisms of transport and how soil, water, and contaminant properties affect the ability of contaminants to migrate.

#### Infiltration Through the Vadose (Unsaturated) Zone

The vadose zone is found in the SSA soils and the uppermost stratigraphic units, the alluvium and the Denver Formation. Infiltration of contaminants sorbed to the soil is controlled by the tendency of the contaminants to desorb from the soil phase and into the water infiltrating the vadose zone. The ability of the contaminant to desorb is not just a function of the chemical constituent itself, but also a function of the physical and chemical properties of the soil, including texture/structure, clay mineralogy, cation exchange capacity, and organic carbon content. Infiltration of contaminants through the vadose zone is also controlled by the physical nature and setting of the media in this zone. For example, sandy soils and closed depressions allow surface water to infiltrate the vadose zone and recharge the unconfined aquifer. Infiltrating surface water may leach contaminants that will desorb from soils present at the surface and in the vadose zone.

In soils with slightly higher percentages of clay, minerals, and organic carbon, such as those in the Sand Creek Lateral and lake sediments, contaminants would be expected to leach slowly to the lower profiles. In the SSA, contaminant movement appears to become restricted by clay zones at lower depths leading to the water table. Possible examples of this process include the ditch that bisects the Section 12 buried lake sediments, leading from Lower Derby Lake to Rod and Gun Club Pond, the inlet channel to Lake Ladora, and the Uvalda Ditch in Section 11. Sediments in these source areas contain a large quantity of clay minerals and organic matter. Concentrations of several analytes in surface materials exceed concentrations in underlying and downstream sediments. These results suggest the possibility that contaminant movement through Vadose Zone by infiltrating water is being greatly restricted (both vertically and laterally) by the absorbing capability of organic matter. Another possibility is that the presence of organic matter may increase the microbial population resulting in degradation of co-metabolization of incident compounds. The alluvium in the SSA varies in

thickness and consists primarily of unconsolidated, poorly graded sands, with lesser amounts of silts and clayey sands. Unconsolidated sediments are considered highly permeable and capable of easily transmitting pollutants into the groundwater (Fetter, 1980).

The infiltration potential of organic compounds is primarily a function of its aqueous solubility and soil/water partition coefficient ( $\log K_{ow}$  or  $\log K_{oc}$ ). The OCPs in the SSA have low water solubilities (less than 1 mg/l) and high  $\log K_{ows}$  (3.2 to 7.4), and therefore have a high affinity for soils. Consequently, OCPs are less likely to leach through soils than other organic compounds (Thompson & Edwards, 1974). DBCP has a moderate water solubility (1,230 mg/l) and a moderate  $\log K_{ow}$  (2.43). These values indicate that DBCP will tend to sorb to soils, but some will partition into water that is in contact with the soil. The VHOs, VHCs, VAOs and SHOs present in the SSA have moderate to high water solubilities and  $\log K_{ows}$ . They therefore have a tendency to partition into water and readily leach to underlying groundwater.

Arsenic's solubility is less than 1,000 mg/l, while mercury has a solubility of 56 mg/l. Compounds with solubilities less than 1,000 mg/l are generally considered insoluble (in a qualitative sense). However, arsenic and mercury can mobilize under appropriate oxidation and pH conditions. Therefore, they may be present on the soil surface and in the water phase.

#### Surface Water Transport

Surface water is a significant migration pathway resulting in downgradient transport of contaminants sorbed to surface soils or sediments and transport of contaminants dissolved in these waters. OCPs, several groups of volatile organic compounds, DBCP, arsenic, and mercury all sorb to soil or sediment surfaces or may be carried in surface water (Kaufmann, 1983). An example of the transport potential of surface water is evidenced by deposition of contaminants in sediments downstream of South Plants. Whether an analyte is carried in aqueous or solid phase depends upon its chemical behavior in water as well as characteristics of the soil media.

Texture and moisture content are two key soil characteristics affecting run-off rates. For example, the transport of organic and inorganic contaminants through surface run-off would be greater from finer textured soils than from coarser textured ones (Merkle & Bovey, 1974). The loss of OCPs from moist soils may be twice as high as from drier soils. Whether sorbed to sediments or soils or dissolved in surfact water compounds lie VHOs and VAOs are likely to volatilize as they are transported away from their source.

#### Eolian Transport

Particle size and bulk density are two key factors in affecting eolian transport of soil, finer particles travel greater distances than coarser, heavier ones. Wind speed also impacts the momentum with which airborne particles will travel (Hartley & Graham-Bryce, 1980). The most erodable particles are considered to be about 0.1 mm in diameter and smaller. It is not entirely clear that eolian transport of compounds is an important migration mechanism under current conditions in the SSA. However, the dispersion of dieldrin south and east of South Plants into nonsource areas of Section 1 may have resulted from wind dispersion. Furthermore, air quality monitoring during the RI program found that relatively high levels of TSP and metals occurred along the southern boundary of the SSA. These elevated occurrences were observed during winter months, when winds originate predominantly from the west and south. The most likely source of high TSP in the SSA is along 56th and Havana Streets and is probably associated with sanding of roadways. Results from another monitoring station located in the northern portion of the SSA (AQ6) are indicative of general background concentrations in an urban setting.

#### Groundwater Transport

Groundwater transport is facilitated by the processes of advection and dispersion. Advection is the process by which contaminants are transported by the bulk motion of flowing groundwater. It is the primary process by which solutes migrate in coarse grained, permeable aquifers. Dispersion results from the processes of molecular diffusion and mechanical mixing.

Molecular diffusion represents the tendency for ionic and molecular species to move under the influence of their kinetic activity. Mechanical mixing involves variation in groundwater velocity caused by frictional forces, variability in pore dimensions, and variability in localized flow direction (Mackay et al., 1985). Dilution tends to result from dispersion; therefore, maximum concentrations of an analyte diminish with distance from the source.

#### Soil Vapor Transport

Migration of some volatile organic compounds detected in the SSA has partially resulted from the process of soil vapor transport. Such compounds may have included DBCP, VHOs, and VAOs. The degree of vapor movement is determined not only by chemical volatility of the contaminant, but also by the adsorptive properties of the affected soil.

The amount of chemical volatilization from soil is also highly dependent on the fractionation of the contaminant in the solid, liquid, and vapor phases. Use of quantification modeling for chemical properties such as partition coefficient calculations between water and air, water and soil ( $K_d$ ), and water and biota ( $K_{ow}$ ), vapor pressure, soil gas measurements from contaminated soils overlying shallow aquifers, and solubility data are useful in developing conclusions regarding movement of contaminants via soil vapor transport.

#### Bioaccumulation

Results of RI and previous biota investigations in the SSA and in other areas of the RMA, have suggested that bioaccumulation has occurred and has resulted in phytotoxic effects to both plants and animals. For the purpose of this report incidental ingestion of contaminated soils, plants or other lower trophic level species is considered as a bioaccumulation process. Many factors affect the ability of plants and animals to absorb contaminants, including physical/chemical characteristics of affected soils, particularly organic matter content, concentration, solubility, partition coefficients ( $K_d$  and  $K_{ow}$ ), and ionic form of the particular contaminant, temperature, moisture content, microbial activity, season, plant and animal species and tissue type, percent cover, plant vigor, and animal migratory patterns (USEPA, 1983; Rouchaud & Meyer, 1982; Kaufmann, 1983).

### Anthropogenic Transport

Anthropogenic transport is defined, for the purposes of this report, to include any human activities that result in contaminant migration that would otherwise not occur. Examples of anthropogenic transport in the SSA include: 1) transport of potentially contaminated soil, mud, or dust adhering to vehicles; and 2) ground surface modifications including excavations, grading, or fill placement of potentially contaminated materials (i.e., ditch maintenance in Sections 1 and 2, road grading along several rights-of-way).

The significance of the first anthropogenic mechanism is difficult to assess. Numerous scenarios can be hypothesized in which exposures resulting from this mechanism could be widespread. However, present practices at the RMA are specifically designed to prevent or reduce further spreading of contaminants by this mechanism. Consequently, this mechanism will not be considered in light of the migration pathways discussions. The second anthropogenic mechanism remains a potential factor in assessing contaminant fate and transport. Emergency actions, such as filling lakes and ditches with runoff, filling sandbags during rain events, or regular ditch maintenance activities, have the potential for spreading contaminants into other environmental media. The disposal, in 1964 and 1965, of lake sediments containing contaminants in Sections 11 and 12 may be considered anthropogenic transport, although it was a past transport mechanism and is not currently affecting migration of contaminants from these areas.

### Potential Receptors of Contaminants

As defined in the introduction of Section 3.0, an evaluation of potential contaminant receptors is an inherent part of the RI program. Both biological and physical receptors were considered in the evaluation. Five receptors were identified in the contamination assessment for the SSA. These include: soil as sediments delivered downgradient within the study area or off-site; surface water delivered downgradient or off the SSA toward the Western or North-Central Study Areas; groundwater delivered off the study area, primarily in a northwesterly direction; sensitive biota populations that are commonly found in the SSA; and, human populations that could come in direct contact with potentially contaminated materials.



Dispersion of potentially contaminated soils, as sediments entrained in run-off, depends upon the direction and rate of surface water flow, soil profile characteristics (texture, percent clay, etc.), surface evaporation rates, and the chemical behavior of the contaminant in contact with sediments (i.e. solubility of the pesticide in water). Other factors influencing surface water transport include slope gradient, vegetative cover, and moisture content of the soil. Since pesticides leach more readily into sandy than clayey soils, loss of pesticides to downgradient sinks is enhanced when contaminants come in contact with fine-textured materials. In the SSA, the greatest propensity for downstream sediment deposition occurs via the ditches, lakes, and ponds.

The receptors for much of the potentially contaminated surface water and groundwater lie beyond the boundary of the SSA. The locations where surface water can leave the SSA are Sand Creek Lateral in Section 2, the overflow basin in Section 3, and, occasionally the Upper Derby Overflow in Section 6. Several contaminants appear to be transported throughout the SSA in surface water. The analytes are carried on entrained sediments. Contaminants dissolved in aqueous phases are carried to a lesser extent to these sinks.

Groundwater is also a potential receptor of contaminants from the SSA soils. Groundwater flows into the SSA from both the south-southeast and the north towards the lakes, which function as a hydraulic divide. Depth to groundwater beneath the ditches north of the lakes ranges from less than 10 ft beneath the Section 1 ditches to over 30 ft beneath the Sand Creek Lateral in the northwest portion of the SSA. Depth to groundwater beneath the remaining sites in the SSA is generally less than 20 ft. Mobile contaminants may leach from the soils in the SSA sites, including the lake bottoms, into the groundwater. Contaminated groundwater can move from the SSA to the northwest and northeast, contaminating groundwater outside of the SSA.

Several analytes or their derivatives were found to have entered both primary consumer (herbivore) and secondary consumer (carnivore) elements of the food chain at RMA. Continuous exposure to contaminants by aquatic organisms and migratory waterfowl is difficult to assess. Bioaccumulation can and has

affected several sensitive species of biota to a degree that varies with trophic level, life span, specific food web membership, patterns of movement, reproductive frequency, and physiology.

Several routes of human exposure to potential contaminants are possible. These routes may occur on-post although off-post exposures may be considered and include (but are not be limited to): ingestion of potentially contaminated drinking water, consumption of potentially contaminated transitory biota, and inhalation of airborne contaminants. Risks to human receptors are not addressed in this report.

Except for human receptors, each of the remaining four receptors will be discussed for the analyte groups presented in the following subsections. These discussions will detail potential receptors of individual or groups of analytes, possible migratory pathways to a particular receptor or sink, and environmental consequences of this exposure.

#### 3.3.1 Volatile Halogenated Organics

VHOs were detected sporadically throughout the SSA. The VHOs detected in soil include the following:

- o Methylene chloride
- o Chloroform
- o 1,1,1 Trichloroethane
- o Carbon tetrachloride
- o 1,1,2,2-Tetrachloroethane

VHOs identified in the surface water include the following:

- o Chloroform
- o 1,1,1 Trichloroethane
- o Carbon tetrachloride
- o Tetrachloroethylene
- o Chlorobenzene

VHOs detected in groundwater from the water table aquifer (WBZ 1A-1) include:

- o Chloroform
- o 1,1,2-Trichloroethane
- o 1,1-Dichloroethane
- o 1,2-Dichloroethane
- o 1,1-Dichloroethylene

- o 1,2-Dichloroethylene
- o Carbon tetrachloride
- o Chlorobenzene
- o Tetrachloroethylene
- o Trichloroethylene

VHOs detected in groundwater from Denver Formation WBZ-2 include:

- o Chloroform
- o 1,1,2 - Trichloroethane
- o 1,1 - Dichloroethane
- o 1,2 - Dichloroethylene
- o Carbon Tetrachloride
- o Chlorobenzene
- o Tetrachloroethylene
- o Trichloroethylene
- o Methylene chloride

Finally, VHOs detected in groundwater from Denver Formation WBZ-3 and 4 include:

- o Chloroform
- o 1,2-Dichloroethane
- o Chlorobenzene

VHOs have moderate to high aqueous solubilities and volatilities, and partition slowly onto organic matter. This analyte group tends to move rapidly from shallow soils to air and groundwater by volatilization and infiltration, respectively. These analytes also have a high propensity to mobilize vertically and areally at moderate to rapid rates when in water. In groundwater systems, where VHOs have been primarily detected in the SSA, photolysis is insignificant and losses due to volatilization minimized as a result of slow upward diffusion rates within the unsaturated zone. Abiotic transformation to decreasingly halogenated compounds may occur under increasingly reduced conditions (Vogel et al., 1987). Bioconcentration factors for this group range from a low to high and have low biomagnification potentials.

#### 3.3.1.1 VHO Migration Pathways

In the SSA, surface water, groundwater, and vapor transport are the key migration pathways for VHOs, given their moderate to high solubilities and volatilities, and low potential for partitioning onto the soil. VHOs were found in the SSA primarily in surface water and groundwater, and rarely in

soils, which further supports the conjecture that surface water and groundwater are the primary pathways. In addition, the VHOs found in the surface water and groundwater do not appear to be associated with any of the VHOs found in the soils.

VHOs detected in soils in the SSA included methylene chloride, chloroform, carbon tetrachloride, 1,1,1-trichloroethylene, tetrachloroethylene, and 1,1,2,2-tetrachloroethane. Most of these detections were at low concentrations, in one sampling horizon, and/or randomly distributed. The only area that contained spatially related detections of a VHO was the Section 3 overflow basin. This area contained multiple detections of 1,1,2,2-tetrachloroethane, including one boring with detections from the ground surface to a depth of 10 ft. Since depth to the groundwater is 10 to 20 ft in this area, the 1,1,2,2-tetrachloroethane has the potential to leach into the water table and could be carried downgradient in the groundwater of WBZ 1A. However, the overflow basin lies at the western edge of the SSA, and groundwater flows from the site into the WSA. Therefore, any 1,1,2,2-tetrachloroethane moving from this site would only be detected in Section 3 wells.

VHOs were most often detected in the SSA in surface water and groundwater downstream and downgradient from the SPSA, the apparent source. Of the VHOs detected in surface and groundwater, chloroform was the most commonly detected. Chloroform was detected in surface water in the Section 1 and 2 ditches by previous studies in 1980 and 1983, as well as during the RI in 1986 and 1987. The Section 1 ditches empty into the lakes, although chloroform was not detected in surface water flowing in them during any of the sampling. Chloroform was detected in WBZ 1A wells throughout the northern half of the SSA (in SSA Wells 01041, 01030, 01047, and 02577), between the SPSA and the lakes. In the northeast and northwest corners of the SSA chloroform was detected in WBZ 1A Wells 02014, 02008, 03005, and 01051. All the SSA wells in which chloroform was detected are downgradient of the SPSA, except for one well on the south side of Lower Derby Lake, Well 01051. Chloroform was also detected in WBZ 2 Wells 02038, 02024, 02035, and 02021 located downgradient of South Plants. These wells detected nearly the same set of contaminants as the

WBZ 1A-1 wells (for example, SSA Well 02020) located next to them. This indicates a hydraulic connection between the two water bearing zones and is supported by the geology. In this area, the southwest side of South Plants, WBZ 2 sands subcrop and the head difference between WBZ 1A-1 and WBZ 2 indicates that groundwater is probably moving from WBZ 2 into WBZ 1A-1 (see Figures SSA 1.4-7 and 1.5-15). In Wells 02020 and 02021, both wells are screened in sands which are separated by a thin claystone bed (see cross-section SS3-SS3', Plate SSA 1.4-1). The head difference between WBZ 1A-1 and WBZ 2 indicates that the groundwater is probably moving from WBZ 1A-1 into WBZ 2. Chloroform was also detected in two deeper wells screened in WBZ 3 and WBZ 4, one located in the northeast corner of the SSA and one located in the northwest corner (SSA Well 02010). Chloroform was also detected in shallower wells clustered with these deeper wells. The head difference in the vicinity of these wells is not known, though the head difference map (Figure SSA 1.5-16) normally indicates that the potential for groundwater movement is from WBZ 2 to WBZ 3.

The remaining VHOs are primarily solvents that were detected in WBZ 1A-1 and WBZ 2, on the south side of SPSA, immediately northeast of Lake Ladora. These VHOs appear to be moving in the groundwater away from South Plants towards Lake Ladora. VHOs were also detected in samples from WBZ 3 and WBZ 4 from the northeast and northwest corners of the SSA. The VHOs probably migrated into the lower water bearing zones via possible fractures in the overlying clay or along improperly completed wells.

Anomalous detections of VHOs have also been found in the SSA south of the lakes in soils, surface water, and groundwater. There are no historically documented upgradient or upstream sources on RMA for these contaminants. Analysis of 1 sample out of 4 collected from Well 01021 detected chlorobenzene at 1.3 ug/l. Analysis of the only sample collected from Well 01051 detected: 1,1 Dichloroethylene (3.9 ug/l), chloroform (4.8 ug/l), and trichloroethylene (0.96 ug/l). Analysis of 1 sample out of 4 collected from Well 07001 detected chlorobenzene at 1.9 ug/l. None of these VHOs were detected in any soil sample collected from Site 12-1.

Wells 01001 and 12009 were not sampled during the RI. However, some historical groundwater data is available for these wells. Samples from Well 01001 were only analyzed for these wells. Samples from Well 01001 were only analyzed for DBCP, DCPD, and DIMP. Samples from Well 12009 were only analyzed for aldrin, arsenic, ICPs, and toluene. Samples were never analyzed for VHOs.

Based on these results, the 1 out of 4 detections in Wells 01021 and 07001 are most probably due to something other than actual contamination, such as inadvertent laboratory or field contamination.

The detections in the sample from Well 01051 may also be attributed to inadvertent laboratory or field contamination, considering that none of these contaminants were found at Site 12-1 nor in any of the surrounding wells. However, the Montbello industrial area south of RMA could contribute the VHOs found in these media. VHOs may be migrating from south of RMA to the lakes and the Havana Street Interceptor Ponds, in the surface water entering RMA via the Sand Creek Lateral, Peoria Ditch, Uvalda Ditch, and Highline Lateral. The detection of VHOs in groundwater in the Southeastern portion of the SSA was a one-time occurrence and may have been a product of field sampling error or lab error.

The VHOs may be migrating from the soils in the overflow basin and the groundwater by vapor transport. Because of the high potential for volatilization of the VHOs, they may be moving both vertically and horizontally through the sandy soil and alluvial material, eventually moving upwards to the ground surface. This high volatility may also be the reason why the VHOs are not seen in the surface water in the lakes are widespread in soils in the SSA.

Roughly 25 percent of the VHO detections in soil were of methylene chloride. This common laboratory contaminant was reported at concentrations below 5.0 ug/g but was not reported in companion method blanks. Although methylene chloride is a common laboratory contaminant, there are several documented examples of its occurrence in the SSA. The 1983 USAEWES study of Lake Ladora did confirm its presence in lake sediments and surface water samples. The

1985 Dames and Moore study also found methylene chloride entering RMA in surface water in the Peoria and Uvalda Ditches. It is not found in groundwater in the SSA. Methylene chloride was used in the production of several organic compounds, including bidrin, azodrin, dichlor and other products. Several buildings in RMA have been associated with the use of methylene chloride, including Buildings 412, 414, 415, 428, 431, 514, 525 and Tank 1279 north of Building 525 (South Plants Study Area Report, draft final, 3/89). Drainage from these areas may have directed flow toward the lakes area, where it has in turn been historically detected in waters and sediments.

In conclusion, VHOs are found moving in surface water and groundwater from the South Plants area towards Upper and Lower Derby Lakes, Lake Ladora, and into the Eastern Study Area (ESA) and Western Study Area (WSA). The few VHOs found in the soil in the SSA do not appear to be related to the groundwater and surface water VHOs and are possibly moving into the groundwater only at the overflow basin.

#### 3.3.1.2 Potential VHO Receptors

Based on the conclusions of the previous sections on VHO sources and migration pathways in the SSA, the potential receptors for VHOs are surface water, groundwater, air, and biota.

The lakes in the SSA may be receiving VHOs from South Plants via the ditches. The lakes and Havana Street Interceptor Ponds may also be receiving or could potentially receive VHOs from south of RMA via the pathways identified previously. However, widespread contamination of surface water by VHOs is not evident in the SSA.

The VHOs migrating in groundwater from the South Plants may enter the lakes, particularly Lake Ladora and to some degree Lower and Upper Derby Lakes. In addition, VHOs may migrate to the lakes from contaminated groundwater entering RMA from the south. Again, this condition is not supported by sampling data. 1,1,2,2 Tetrachloroethane may migrate to the groundwater from the overflow basin.

Air is also a possible receptor of VHOs in the SSA. As discussed earlier, VHOs have moderate to high volatility and migrate through the subsurface by vapor transport. The VHOs could move from the subsurface to the air in areas where there are soils, surface water, or groundwater in which VHOs were detected. This would include the overflow basin, the Section 1 and 2 ditches, Lake Ladora, and areas of Sections 1 and 2 in which VHO groundwater contaminants are present.

Three VHOs were found in the SSA that are of concern to biota. They are chlorobenzene, chloroform, and trichloroethylene. Only chlorobenzene appears to bioaccumulate and bioconcentrate. Because chlorobenzene has historically been detected in biota on RMA, there is a potential exposure route through ingestion of lower food chain biota by predators. Chlorobenzene may cause adverse effects at concentrations found in SSA surface waters (Calamari et al., 1983; Birge et al., 1979). The major exposure pathways for terrestrial wildlife for the VHOs are ingestion of surface water and incidental soil ingestion. Aquatic life are exposed to potentially contaminated sediments and water.

### 3.3.2 Volatile Hydrocarbons and Related Compounds (VHCs)

Volatile hydrocarbon (VHC) compounds were detected mostly in an area north of Lake Ladora and Lower Derby Lake and near the South Plants boundary, but they were also detected at other locations throughout the SSA. The VHCs detected in soil include the following:

- o Methylisobutyl ketone
- o Dicyclopentadiene

In surface water, the detected VHCs include the following:

- o Methylisobutyl ketone
- o Dicyclopentadiene
- o 2-Pentanone
- o 4-Hydroxy-4-methyl-2-pentanone

VHCs detected in groundwater from the water table aquifer (WBZ 1A-1) include:

- o Dicyclopentadiene
- o Bicycloheptadiene



1

Methylisobutyl ketone and 4-hydroxyl-4-methyl-2-pentanone have high solubilities and moderate vapor pressures. These compounds have a high propensity to volatilize from surface soils and waters. Because of their high solubilities, these compounds may leach rapidly through permeable media such as coarse grained soils or sandstone, and they may be transported in water over larger distances. Dicyclopentadiene, bicycloheptadiene, and 2-pentanone have lower solubilities but moderate to high vapor pressures. These compounds are also likely to volatilize from surface soils and waters but because of their lower solubilities are not as likely to be leached or transported in water to the extent of those with higher solubilities.

#### 3.3.2.1 VHC Migration Pathways

In the SSA, the identified migration pathways for analytes in this group include vapor transport, groundwater, and surface water. VHCs were detected in soils, surface water, and groundwater; however, the occurrences in each medium do not appear to be related.

VHCs were only detected in two soil samples. Dicyclopentadiene was detected once in the Section 1 trash dump and methylisobutyl ketone was detected once in Lake Ladora sediments. The detection of dicyclopentadiene is most likely related to disposal operations at this site.

VHCs were detected in surface water from Section 1 and 2 ditches, inside and along the SPSA boundary, during three different sampling events (three different years), and are probably also related to sources in SPSA. VHCs, however, were not detected downstream of these occurrences, and probably volatilized from surface waters as they migrated downstream. VHCs detected in the Peoria Ditch, along the southern border of the SSA, do not appear to be related to on-post VHC sources. Rather, these detections are probably related to unidentified off-post sources, but volatilized before contacting source areas further downgradient on RMA.

The distribution pattern of VHCs in groundwater roughly coincides with the pattern exhibited by the benzene, VAO, and VHO plumes in Sections 1 and 2 of the SSA, with the exception of an isolated dicyclopentadiene detection

reported north of the Section 3 overflow basin (in Well 03005). The VHCs detected in groundwater in Sections 1 and 2 probably migrated from one or more sources in the SPSA, through the fractured claystones of WBZ 1, and to their current locations in the SSA. As expected, concentrations of VHCs tend to be elevated near the South Plants boundary and decrease downgradient from this boundary in Wells 02577 and 02505. The isolated detection in Section 3 appears to be unrelated to South Plants sources. The dicyclopentadiene (DCPD) was only detected in 1 sample out of 4 collected at a concentration of 13 ug/l. None of the upgradient wells, nearer to the South Plants area, detected DCPD in any of the samples collected from them. In addition, DCPD was not detected in any of the soil samples collected from any of the sites located in the SSA upgradient of this well. This detection may be due to inadvertent laboratory or sampling contamination and does not represent actual groundwater contamination.

#### 3.3.2.2 Potential VHC Receptors

Because VHCs have volatilized out of surface soils in the SSA, it is not likely that they would be hydrolyzed into surface water. However, both methylisobutyl ketone and dicyclopentadiene were detected in surface water in South Plants as recently as 1987. Therefore, there remains a potential source of continued influx of these compounds into surface water in the SSA. The VHCs in surface water flowing from South Plants ditches or Section 12 ditches are likely to volatilize before reaching the lakes in the SSA; however, the lakes could still be exposed to VHCs from this pathway.

VHCs in groundwater appear to be migrating downgradient away from their source in the SPSA. The vertical extent of VHC contamination in groundwater is contained in WBZ 1 and 1A. The contaminants in this area, dicyclopentadiene and bicycloheptadiene, will likely follow the groundwater flow patterns and migrate southwest of their current position. Ultimately, the receptor for the VHCs would be Lake Ladora since groundwater recharges the lake.

The sparse distribution of VHCs in the SSA does not present a high exposure to potential biota. However, the possibilities for exposure do exist in that VHCs could be transported into the lakes and enter aquatic systems. Biota are

moderately to highly sensitive to dicyclopentadiene, but it does not bioaccumulate. The major exposure pathways to wildlife in the SSA are by incidental soil ingestion. Plants do not accumulate dicyclopentadiene, and it does not bioaccumulate in aquatic ecosystems; therefore, a food ingestion pathway does not exist. Aquatic life is exposed by direct contact with surface water and sediments. Since the compound was not detected in the lakes, there is negligible exposure risk. The compound has never been detected historically in biota at RMA.

### 3.3.3 Volatile Aromatic Organics (VAOs)

In the SSA, toluene was the only VAO detected in soils. In the surface waters of the SSA, the following VAO compounds were detected:

- o Benzene
- o Toluene

The VAOs detected in the groundwater of the SSA (WBZ 1 and WBZ 2) include the following:

- o Benzene
- o Toluene
- o Ethylbenzene
- o m-Xylene
- o o- and p-Xylene

The VAO compounds exhibit moderate aqueous solubilities and high volatilities for all but m-xylene, which has a moderate volatility. The volatile nature of the VAOs explain the relatively infrequent occurrence and low concentrations of these compounds in soils and surface water, compared to their occurrence and concentrations in groundwater. The VAO compounds also have a low affinity for organic matter and clay minerals, and tend to mobilize at moderate rates. In flowing surface water, compounds such as toluene and benzene tend to degrade rapidly, although they may travel in these waters over large distances. Some bioconcentration of xylenes may occur, although for other VAOs, bioconcentration and bioaccumulation potentials are low.

#### 3.3.3.1 Migration Pathways

In the SSA, surface water, groundwater, and vapor transport represent the major pathways for VAO migration. Though minimal exposure to biota is

apparent, Bioaccumulation by exposure to biota is also considered a minor pathway. As with the previous groups of volatile organic compounds, VAOs were primarily detected in groundwater, and are distributed fairly uniformly in an area north of Lake Ladora and Lower Derby Lake near the SPSA border. Detections of VAOs in surface water and in soils are much less frequent and uniform than those in groundwater. Moreover, these detections are probably not related to groundwater occurrences of VAOs. Considering the frequency of occurrence and distribution of VAOs, and the chemical nature of these compounds, groundwater represents the major pathway for VAO migration in the SSA.

In the SSA, toluene was the only VAO detected in soils. It occurred once south of the Section 11 buried lake sediments, at low concentrations. It also occurred once at low concentrations in the Section 1 ditches that feed into Upper Derby Lake.

VAOs detected in surface water in the SSA include benzene and toluene. Both of these compounds were also detected in samples from ditches on or near the SPSA border at moderate concentrations (1-40 ug/l). However, these VAOs were not detected in downstream samples and probably volatilized as they migrated through these waters. Toluene was detected in surface waters from the Peoria Ditch, which empties into the Havana Street Interceptor Ponds, where benzene was detected. Along the southern border of the SSA in Section 12, toluene was also detected in surface waters. Since this area is upstream from RMA there is no obvious RMA-related source of these three detections. The Montbello industrial area south of RMA could potentially be a source for the VAOs that have migrated onto the SSA.

Benzene was the most commonly detected VAO in the groundwater in the SSA (see Section 3.5, Figure SSA 3.5-5). Benzene was detected frequently in an area in Section 1 near to the South Plants border. It appears to originate in the southern portion of the South Plants area.

Benzene, a liquid solvent, was used in production of pesticides in the South Plants, and is a component of gasoline. It was primarily used and stored in

South Plants Study Area sites SPSA-1 and SPSA-3; Buildings 745A, 745B, 745C, 746 and Building 328. Other probable sources of benzen in the SSA were spills at undocumented locations in the Southern portion of South Plants and in unlined ditches downstream from SPSA Buildings 422 and 472A (Ebasco, 1986c/RIC 88286R10). Benzene detected in Section 12 wells were one time occurrences and there is no evidence of a potential source located upgradient of these wells.

Only one well reported benzene co-occurring with toluene, ethylbenzene, m-xylene, and o- and p-xylene. These compounds were detected in 1986 and 1987 in a WBZ 1 Well 01014, which is located along the SPSA border of Section 1. The VAOs other than benzene do not recur in downgradient Wells 02505, 02577, or 02020, or in a deeper cluster Well 01015. Adjacent wells (01557, 01558, and 01556) were sampled by Shell during 1988 and only benzene was detected; however, dilution factors used in the analyses of the Shell samples could possibly have raised detection levels to the point where other VAOs may not have been detected. Benzene detected in this well and in nearby wells were reported at elevated concentrations. These wells were all screened in the Denver Formation claystones which tend to subcrop in this area. Benzene detected in downgradient WBZ 1 wells was also reported at two or three orders of magnitude less concentration, but was probably spatially related to benzene in the upgradient wells. Anomalous detections of benzene were reported in deeper wells (12003, 01023, and 02025) and were probably not related to the detections near South Plants. One detection was reported in a WBZ 2 well in the center of Section 12, the other two were from WBZ 3 wells in Sections 1 and 2. All three detections were less than 10 ug/l.

#### 3.3.3.2 Potential Receptors

Considering the limited detections and low concentrations of toluene in the SSA soils, the migration potential of this compound is low. Toluene would probably volatilize before being transported further by surface water run-off, or before infiltrating into deeper soil intervals. Volatilization is also the most probable fate of VAOs in surface water, given the volatile nature of VAOs and the fact that ditches in the SSA only carry water intermittently. VAOs have been transported from off-post locations to the Havana Street Interceptor Ponds, where they will probably volatilize before entering sediments or

groundwater. VAOs have not been detected in any of the lakes downstream from the Section 1 and 2 ditch waters, which further supports conjecture that VAOs are likely to volatilize during transport through the ditches.

The VAOs in groundwater may enter Lake Ladora and possibly Lower Derby Lake as they migrate downgradient from the SPSA. VAOs in groundwater to the south of the lakes would possibly enter the lakes, as well. The VAOs may also migrate into deeper water bearing zones of the Denver Formation. The head differences between WBZ 1A-1 and WBZ 2 indicate that the potential for groundwater movement is from WBZ 1A to WBZ 2, in the area of the VAOs south of South Plants.

The air is a likely receptor of VAOs from all media in the SSA. As mentioned earlier, the VAOs have moderate to high volatilities and may volatilize from groundwater and soils to the air or to surface water, where they would ultimately degrade or volatilize.

The three VAO contaminants of concern to biota in the SSA (ethylbenzene, toluene, and xylene) do not tend to bioaccumulate. They have not been detected in biota in the SSA and potential exposure to biota is minimal. The major exposure pathway for wildlife is by incidental ingestion of contaminated soil and forage. There is little accumulation potential in plant tissue, and little chance that biota other than plants will contact groundwater.

#### 3.3.4 Organosulfur Compounds - Herbicide and Mustard Agent-Related (OSCs)

No OSCs were detected in the soils in the SSA. In the surface water, only benzothiazole was detected. The OSCs detected in groundwater in the SSA include the following compounds:

- o Chlorophenylmethyl sulfide (herbicide-related)
- o Chlorophenylmethyl sulfone (herbicide-related)
- o Chlorophenylmethyl sulfoxide (herbicide-related)
- o 1, 4-Oxathiane (mustard agent-related)
- o Dithiane (mustard agent-related)

OSCs (herbicide-related) have low to moderate solubilities, moderate to high volatilities, and low to moderate affinities for soil organic matter. The

resultant mobilities of OSCs range from moderate to high, depending on the particular compound of interest. Chlorophenylmethyl sulfide is the least mobile compound of the group, exhibiting a limited potential for leaching from soils, and a retardation in groundwater transport rates because of its low solubility. Volatilization of this compound from soils is also limited. The remainder of this group is moderately mobile in groundwater and may also be transported on suspended sediments in surface waters.

Microbial degradation of herbicide-related OSCs has been reported, although data regarding the rate and extent of degradation and the resulting products are unavailable. Chlorophenylmethyl sulfide has been reported to chemically oxidize to chlorophenylmethyl sulfoxide. Half-lives in soil range on the order of months to years for the group. Bioconcentration or biomagnification is possible for chlorophenylmethyl sulfide, but unlikely for the remainder of the group.

The OSC mustard-agent related degradation products are moderately to highly soluble, exhibit low volatility in water, and are weakly adsorbed to soil organic matter. As a result, they are considered highly mobile in the environment and will be readily leached from soils and transported in surface and groundwater. These compounds are susceptible to oxidation and biodegradation, which act as potential degradation mechanisms. High aqueous solubility and low organic partitioning behavior indicate that bioconcentration is not likely.

#### 3.3.4.1 OSC Migration Pathways

The major migration pathways for OSCs in the SSA are vapor transport, surface water transport, and groundwater transport. Neither herbicide-related nor mustard agent-related OSCs were detected in soils or sediments in the SSA.

In surface water, benzothiozole (herbicide-related) was detected in several samples from along the southern boundary of RMA. This was the only OSC detected in surface water and it has no apparent on-post source. This compound probably has migrated from off-post sources south of the RMA to current locations in the SSA. It was not detected downstream or in downgradient wells.

Groundwater contained the majority of herbicide- and mustard agent-related OSCs, which were detected numerous times along the SSA boundary with South Plants and one time north of Lake Mary. Chlorophenylmethyl sulfone was detected on either side of the northern portion of Lake Ladora. These detections probably migrated from an upgradient source in the SPSA and may be related to detections of this compound and chlorophenylmethyl sulfide in nearby deeper wells. Herbicide-related OSCs were also detected in groundwater north of Upper Derby Lake at relatively high concentrations. The detections, however, do not reoccur in downgradient wells.

Mustard agent-related OSCs were detected in two wells along the SPSA border of Section 1, but were not detected downgradient in the SSA, and are probably not related to each other. As with the other OSCs, they have probably migrated from sources in the SPSA through groundwater to their current locations.

#### 3.3.4.2 Potential OSC Receptors

Biota and groundwater downgradient of the lakes are potential receptors of OSCs. OSCs appear to be migrating through groundwater away from South Plants. Potential receptors include the lakes, particularly Lake Ladora and to a lesser extent Lower Derby Lake. OSCs in groundwater near Lake Mary appear to be migrating to the west and probably will migrate further towards the Section 3 overflow basin and into the WSA.

The air in the SSA represents another potential receptor for OSCs in surface water, and to some extent, OSCs in groundwater. OSCs found migrating through the surface water in the southern portion of the study area will probably volatilize before reaching downstream lakes; however, the lakes would also be an ultimate receptor for these contaminants. Some volatilization of OSCs from groundwater is likely as well as they migrate away from South Plants.

OSCs do not tend to bioaccumulate in biota. The major route of exposure for wildlife is from ingestion of contaminated surface water. Biota other than plants are not expected to contact the groundwater. Although OSCs were not analyzed in SSA biota, there is historical evidence of 1,4-oxathiane in aquatic snails the North Bog in Section 24. Historical data also found



herbicide-related OSCs in tissues of mallards and mourning doves in the lakes region, as well as in prairie dogs, grasshoppers, and browse vegetation in northern portions of RMA.

### 3.3.5 Organophosphorous Compounds - GB Agent-Related (OPHs)

The OPHs detected in the SSA were all GB agent-related. No OPHs were detected in the soils. Dimethylmethyl phosphonate was detected in surface waters, and diisopropylmethyl phosphonate was detected in groundwater.

GB agent-related organophosphorous (OPH) compounds exhibit moderate to high solubilities, low to moderate volatilities, and low affinity for organic carbon. These compounds are considered mobile in the environment, readily leached from soils, and can be transported in groundwater and surface water. The potential exists for limited volatilization from surficial soils and surface water. OPHs hydrolyze slowly in water, with half-lives for diisopropylmethyl phosphonate of 530 years. Measurements on losses of this compound in soils suggest half-lives on the order of 2 years.

#### 3.3.5.1 OPH Migration Pathways

Dimethylmethyl phosphonate was detected twice in surface water from the Section 1 ditches (SSA 2) north of Upper Derby Lake but was not detected in downstream samples. Diisopropylmethyl phosphonate was detected from deeper groundwater wells north and south of Lower Derby Lake in Wells 01022 and 01028. The samples reporting diisopropylmethyl phosphonate were both collected in early 1986, but from different water bearing zones. Well 01022 (WBZ 2) was sampled three more times in 1986 and 1987, and diisopropylmethyl phosphonate was not detected. Well 01028 (WBZ 1) was not resampled. Considering the mobility potential of this compound, surface water and groundwater are the two evident migration pathways, via infiltration and run-off.

#### 3.3.5.2 Potential OPH Receptors

As with the OSCs, downgradient groundwater, downstream lakes, and biota are the principal receptors of OPHs. Air may also be a potential receptor for OPHs from surface water volatilization. Subsequent leaching into deeper

groundwater zones is possible given the chemical behavior of these compounds, and they are likely to migrate to the lakes, particularly Lake Ladora and Lower Derby Lake.

Diisopropylmethyl phosphonate does not tend to bioaccumulate and has little effect on biota at low concentrations (O'Donovan & Woodward, 1977/RIC 81335R08). The potential for exposure of OSCs to plants is negligible due to its absence in surface soils or sediments, and the relative depth of detection in groundwater is well below the penetrable root zone. The presence of diisopropylmethyl phosphonate in surface water may result in minimal exposure to biota. Historical data from RMA has noted low levels of diisopropylmethyl phosphonate in browse vegetation and small mammals. The major exposure pathways for terrestrial wildlife are ingestion of surface water from the ditch areas and ingestion of browse vegetation.

### 3.3.6 Dibromochloropropane (DBCP)

DBCP was detected in several soil and sediment samples from the lakes, from buried lake sediments, and from scattered portions of Sections 1 and 12. DBCP was also detected sporadically in surface water samples collected from Section 1 ditches north of the Derby Lakes. DBCP was detected in eight groundwater samples from four water bearing zones. Six of the detections occurred in alluvial wells (WBZ 1-1A), while the remaining two detections occurred once, each in groundwater from Denver Formation wells in WBZ 2 and WBZ 3, respectively.

DBCP has a moderate aqueous solubility and volatility, and a high affinity for organic matter in soil. It is lost from near-surface soils and surface water by volatilization. Therefore, detectable concentrations in shallow soil horizons are only present within short periods of time following entrainment. Although volatilization of DBCP from surface water is moderately rapid, potential transport distances in most ditches and streams may be significant. Once flushed from shallow soils, DBCP can be moderately adsorbed by soil organic matter and transported at moderate rates by groundwater. It is relatively persistent in subsurface soils and groundwater, but will be decomposed slowly by hydrolysis and microbial action.

#### 3.3.6.1 DBCP Migration Pathways

Surface water run-off, suspended sediment transport, and groundwater transport are the key migration pathways for DBCP in the SSA. DBCP was widespread in Lower Derby Lake sediments and sparsely distributed in Lake Ladora. As noted in Section 2.1, 75 percent of the DBCP detections in Lower Derby Lake occurred in the surface intervals of submerged lake bottom sediments, which indicates that vertical migration by leaching is not occurring to a large extent. The presence of DBCP in surface intervals of the sediments is consistent with its behavior. The clay content exceeds 80 percent in the lake bottom sediments containing this analyte. Studies have shown that a minimum organic carbon content of 0.1 percent is sufficient to be a significant factor in sorption processes (Jury, 1986). The organic carbon content of lake bottom sediments in Lower Derby Lake may be as high as 2.6 percent, thus enhancing absorption of this compound. DBCP was detected most frequently near locations corresponding to the lowest depths in the lakes. It is reasonable to expect that contaminants sorbed to sediments would be transported by lake currents to the deepest levels. DBCP was not detected in Upper Derby Lake, Eastern Upper Derby Lake, Rod and Gun Club Pond, or Lake Mary.

Although DBCP was detected in soils and sediments from Lower Derby Lake and Lake Ladora, it was not detected in surface water from either of the lakes, nor was it detected in wells downgradient from Lower Derby Lake. Apparently, this compound has not migrated into groundwater below or downgradient from sources in these two lakes.

DBCP was not detected in sediments in the Section 1 and 2 ditches and overflow basins in SSA 2. Since RI results and historical data indicate that DBCP was detected in Section 1 ditch surface waters, it is possible that it volatilized from sediments in dry ditches. DBCP may also have temporarily sorbed to organic matter or other suspended particles in the ditch sediments and subsequently flushed into the lakes, or it may have degraded by hydrolysis or microbial action. The absence of DBCP in Section 1 ditch sediments is consistent with its behavior in systems that are characterized by sandy, very permeable surface materials.

The remaining detections of DBCP in soils occurred in the Section 12 buried lake sediments of SSA 3 and in areas of Sections 1 and 12 included in SSA 5. DBCP was not detected in SSA 4 soils. DBCP was detected once in buried lake sediments in Section 12. This was most likely related to the detections of this compound in its predisposed source, Lower Derby Lake. Presently, there does not appear to be a migration pathway for this compound to underlying media.

The sole detection of DBCP in Section 1 soils occurred near a ditch that once delivered process water to Upper Derby Lake. The compound was not detected in the lake sediments, however. Three groundwater wells downgradient of South Plants (01030, 01036 and 01041) contained DBCP, all in WBZ 1, the fractured zone of the Denver Formation. Soils in this area are generally loamy, with interbedded layers of clay loams and sandy clay loams. Organic carbon exceeds one percent in surface layers, but declines rapidly at depth. The mineral surfaces and presence of organic matter in these soils is conducive to in-place sorption of DBCP. Therefore, it is improbable that leaching of DBCP through the unsaturated zone has occurred to the underlying water table. Rather, it is more probable that DBCP has entered the Denver Formation groundwater at an upgradient point in South Plants. DBCP was also detected in wells in the northwest corner of the SSA in WBZ 1A and WBZ 2. The DBCP detection in WBZ 2 was in a sample from well 02038. This detection was not repeated despite repeated sampling. In addition, analysis of samples from the shallow well in this cluster, Well 02037, did not indicate DBCP in the groundwater. WBZ 2 sands subcrop in this area and the gradient indicates groundwater movement from WBZ 2 into WBZ 1. The source of this DBCP is probably the SPSA and indicates that this compound is migrating in groundwater towards the west.

The Section 12 detections of DBCP occurred in sediments in the Uvalda Ditch, approximately one-fourth to one-third mile north of the southern RMA boundary in Section 12. The subsurface soils and alluvium in Section 12 are sandy, permeable, deep, and well-drained, which promote infiltration. General groundwater flow in this area is to the northwest. DBCP was detected in Denver Formation groundwater (WBZ 3), in Well 12004, downgradient of the

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surface detections in the Uvalda Ditch. Two shallower wells in this cluster, 12002 and 12003, were also sampled four times each and DBCP was never detected. This well is located in an open field at least 1/2 mile from any source sites which contain DBCP in soils/sediments.

Given the facts that: DBCP was only detected at very low levels in only 1 of 4 samples from each well; these wells are not located near surface sources of DBCP contamination; and that analysis of samples from the shallower wells in these clusters did not detect DBCP; it is highly unlikely that this contamination was caused by downhole contamination during drilling or due to faulty well completion. Rather, given the nonrepeatable nature of the detections, these detections are likely the result of inadvertent laboratory/field contamination or analysis error and do not indicate actual groundwater contamination.

#### 3.3.6.2 Potential DBCP Receptors

Potential receptors of DBCP include downgradient groundwater, sediments, and biota. Detectable concentrations of DBCP have been found in the groundwater in Sections 1 and 3 moving away from the SPSA, and in Section 12 moving from an unknown off-post source.

The potential exists for further migration of DBCP to downstream lake sediments in SSA 1, if the chemical or physical conditions change in Lower Derby Lake and Lake Ladora sediments. Distance of travel is expected to be minimal, based upon present surface water conditions. The DBCP detected in sediments in Uvalda Ditch could move further downstream to Lower Derby Lake, by surface water transport.

Potential biota receptors include shallow and deep-rooted aquatic vegetation, burrowing animals, and higher trophic-level animals. DBCP causes adverse effects to biota but does not bioaccumulate. The major exposure pathways for DBCP are ingestion of surface water and incidental soil ingestion. Historically, pheasants, bluewinged teal, and mallard been found with DBCP in tissues in the SSA at concentrations up to 0.5 ug/g. Biota other than plants are not expected to contact groundwater on a regular basis. Plants have been

observed to accumulate DBCP residues; therefore, a possible food ingestion pathway exists. Aquatic life may be exposed to DBCP in surface water and sediments, but it has never been detected in aquatic organisms at RMA.

### 3.3.7 Semivolatile Halogenated Organics (SHOs)

Hexachlorocyclopentadiene was infrequently detected in shallow soils throughout the SSA. All detections occurred in association with ditch drainage or disposal operations. The compound was not detected in surface waters or groundwaters.

Of the SHOs analyzed in the SSA, only hexachlorocyclopentadiene was detected. Hexachlorocyclopentadiene is characterized by low solubility and moderate to high volatility and moderate to high affinity for organic matter. It tends to volatilize rapidly from surface water. Half-lives in flowing water range on the order of hours. Its chemical behavior limits its rate of volatilization in the soil environment as well as its potential for infiltration. Mobility in groundwater is also low. Experimental studies indicate that hexachlorocyclopentadiene is not appreciably bioconcentrated, partially due to its rapid transformation by photolysis, hydrolysis, and biodegradation.

#### 3.3.7.1 SHO Migration Pathways

Sediment transport in surface water runoff is the primary migration pathway for hexachlorocyclopentadiene in the SSA. The compound was detected in soils and sediments, but not surface water or groundwater. The majority of the detections occurred in the surface intervals of SSA 1 and SSA 2. The compound was not detected in the sandy, more permeable Section 1 ditch system, but was consistently detected in the Sand Creek Lateral, within clay and organic-enriched sediments. The compound was detected in Upper Derby Lake at the mouth of the Section 1 process water ditch. Organic carbon content in this area ranged from 1.7 percent in the surface intervals to 0.1 percent in subsurface layers. Clays and fine sands predominate in these intervals. Hexachlorocyclopentadiene was also detected in the Section 1 trash dump and adjacent areas, where errant disposal or rain splash erosion may have occurred.

Since hexachlorocyclopentadiene was absent from surface water and groundwater, it is evident that the compound has either volatilized from surface water or readily adsorbed to suspended soil particles, where it flushed into the lakes and ditches. The distance between the clustered detections in Upper and Derby Lake and Sand Creek Lateral suggests that hexachlorocyclopentadiene originated from at least two separate areas in SPSA, each following separate drainage pathways. The affinity of hexachlorocyclopentadiene for organic carbon and clay surfaces prevents its infiltrating into groundwater.

#### 3.3.7.2 Potential SHO Receptors

Hexachlorocyclopentadiene is relatively immobile in groundwater and is not expected to migrate from sediments into the water table. It may be transported for short durations in surface water, but rapid volatilization and affinity for soil surfaces limit the exposure potential in surface water. In biota, there is a minimal exposure risk to hexachlorocyclopentadiene. Its low BCF indicates a low exposure risk to wildlife via biomagnification of residues up food chains (ASTM, 1985). There is little exposure risk to aquatic organisms of hexachlorocyclopentadiene in the SSA (USEPA, 1980b).

#### 3.3.8 Organochlorine Pesticides (OCP)

Organochlorine pesticides (OCPs) were detected throughout the SSA in various media. All seven OCPs were detected in soils and sediments. OCPs identified in surface water include the following:

- o Aldrin
- o Dieldrin
- o Endrin
- o Isodrin

OCPs detected in groundwater from the water table aquifer (WBZ 1A-1) include:

- o Aldrin
- o Dieldrin
- o Endrin

Dieldrin was the only OCP detected in groundwater from Denver Formation WBZ 2. Finally, OCPs detected in groundwater from Denver Formation WBZ 3 include:

- o Aldrin
- o Endrin

No OCPs were detected in groundwater from Denver Formation WBZ 4.

OCPs are generally very persistent in soil environments (with half-lives ranging from 1 to 15 years) and have low solubilities and mobilities in aqueous environments (Edwards, 1973; Holtbold, 1974; Khan, 1980; and USEPA, 1987). Dieldrin is a metabolite of aldrin caused by oxidation processes, endrin is a degradation product of isodrin, and DDE is a by-product of DDT. The distribution of OCPs is a function of the amount of clays or organic matter present in soil. These compounds tend to adhere strongly to naturally occurring organic matter, thereby reducing leaching rates. OCPs have a tendency, however, to leach or migrate in the presence of solvents, such as halogenated or aromatic organic compounds. The chemical nature of OCPs suggests that they may be transported by air or surface water run-off while adhered to fine-textured particles. Appreciable bioaccumulation of OCPs has been noted in biota common to the SSA.

#### 3.3.8.1 OCP Migration Pathways

Surface water is the primary migration pathway for OCPs in the SSA. During and after rain events, ditch sediments are apt to be distributed throughout the lakes (SSA 1) and ditches (SSA 2) with the increased flow. The RI program found that OCPs were distributed throughout the lakes and sorbed to both surface and subsurface sediment samples. As expected, the frequency of detections in soils and sediments is highest in the upstream lakes hydrologically connected to the former process water system.

OCPs were detected most frequently and at the highest concentrations in the surface sediments of the lakes. Clays and silts may account for up to 80 percent of the particle size distribution in lake sediments, thus promoting retention of OCPs in surface intervals. Furthermore, these clays typically contain double-layer minerals that accommodate a larger number of adsorption sites and more surface area from which to inhibit downward or area migration. OCPs were detected in Upper Derby Lake sediments nearly twice as often as in Lower Derby Lake sediments, five times more often than in Lake Ladora sediments, and over eight times as often as in Lake Mary. In Upper Derby



Lake, dieldrin was detected most often, followed by aldrin, chlordane, and DDE. In both Lower Derby Lake and Lake Ladora sediments, aldrin was detected most frequently, followed by dieldrin and DDE. Most samples collected from the lakes contained OCPs at concentrations below 1.0 ug/g. However, highly elevated concentrations of OCPs (up to 55 ug/g) were found in sediments near the inlet to Upper Derby Lake from an abandoned ditch in the Section 1 ditch system and in Lower Derby Lake sediments approximately 750 ft south of an inlet from the Section 1 ditch system (see Figures SSA 2.1-10 to SSA 2.1-15). Concentrations of OCPs in Lake Ladora sediments exceeded 1.0 ug/g in only one sample. OCPs were detected at reduced concentration in the deeper sediments of Upper and Lower Derby Lake and Lake Ladora. This suggests that OCPs did not substantially migrate vertically.

Although relatively small in numerical difference, the geometric mean of organic carbon content in sediments is roughly one-third higher in Upper Derby Lake than in Lower Derby Lake and about two times higher than in Lake Ladora. Corresponding geometric mean OCP concentrations in Upper Derby Lake exceed those in Lower Derby Lake by up to 2.5 times and 3.5 times in Lake Ladora. This points to a general trend in greater retention of OCPs in the presence of organic carbon.

As discussed in Section 2.1, the 1984 U.S. Fish and Wildlife Service (USFWS) study concluded that there was evidence of substantial sedimentation in Lower Derby Lake and Lake Ladora since the time of dredging (Bergerson et al., 1984). Upper Derby Lake was dry at the time the study was conducted. Observations of the sand/silt interface and radioactive dating of the sediments indicate that seven to nine inches of sediment were deposited in Lake Ladora since early 1965, while about 12 to 13 inches were deposited over previously dredged materials in Lower Derby Lake. OCP concentrations below these depths suggest that all previously deposited materials containing contaminants were not dredged from the lakes in the 1960s. In addition, the presence of OCPs in the 0 to 2 ft interval indicate that potentially contaminated sediments are still discharging into Upper and Lower Derby Lakes from South Plants.

Concentrations of OCPs in Lake Mary, Eastern Upper Derby Lake, and Rod and Gun Club Pond sediments were low, and detections were scattered. The only dieldrin and chlordane detections in Rod and Gun Club Pond occurred in surface sediments, immediately south of the point where the Lower Derby Lake overflow ditch empties into the pond.

OCPs were not detected in any surface water samples collected from the lakes during the RI or previous studies dating back to 1980, with the exception of one sample collected from Lake Mary during a 1984 study by the USAEWES. Analysis of this sample detected dieldrin at a very low concentration. Subsequent analyses of samples collected during the RI did not detect any OCPs in Lake Mary.

Despite the fact that OCPs are found in sediments throughout the lakes, and the lakes are believed to be in hydrologic communication with the groundwater, there is a very low potential for the movement of OCPs from the sediments to the groundwater. This is because of the tendency of OCPs to adsorb to clay minerals and organic matter in sediments and the chemically low solubilities of OCPs. In addition, OCPs have not been detected in groundwater downgradient from the lakes. Wells 02052 and 01024 are located downgradient of Lower Derby Lake, and Well 02008 is located cross-gradient from Lake Mary. OCPs were only found in Well 02008. In addition, other contaminants found in this well were not found in Lake Mary sediments. This further supports the theory that the OCPs in the lake sediments are not mobilizing.

However, OCPs are found in several wells located upgradient of the lakes, on the north and northeast sides of Lake Ladora (SSA Wells 02020, 02034, 02008, 01030, and 01031). These same wells in WBZ 1A-1 contain VHOs that may contribute to the mobility of OCPs in groundwater. OCPs are also found in two deeper wells screened in WBZ 2 and WBZ 3, with no associated VHOs. These occurrences are anomalous and may indicate that the WBZs are in hydraulic communication. The WBZ 2 sands subcrop in the area where OCPs were detected in WBZ 2 (Well 02038) and the hydraulic head difference indicate potential for groundwater movement from WBZ 2 into WBZ 1. However, samples from Well 02037 indicate that additional OCPs are present in WBZ 1 that are not found in WBZ 2.

OCPs are not found throughout the soil profile of Eastern Upper Derby Lake sediments as in the other lakes in SSA 1. In this lake, OCPs were only found in surface sediments. Without a consistent influx of surface water, there is little or no transport mechanism that would either contribute new sediments or leach existing contaminants downward into the soil profile. The lack of surface water, absence of OCPs in deeper lake sediments, and the relatively immobile nature of OCPs suggest that the migration potential in this area is low.

The Section 1 and 2 ditch systems in SSA 2 were most affected by the surface water transport migration pathway. These sources contained the greatest abundance and highest concentrations of OCPs in the SSA. The majority of detections occurred along the Sand Creek Lateral north of Lake Ladora, extending further north to December 7th Avenue. In particular, concentrations exceeded 100 ug/g in the lateral, immediately downstream from a ditch exiting South Plants, west of the South Plants sanitary landfill in Section 2. Water was often observed pooling in this portion of the ditch, perhaps promoting infiltration to depths exceeding 5 ft. Dieldrin tended to be the most common of the contaminants detected. This was perhaps due, in part, to the breakdown of aldrin to dieldrin in the natural environment. However, aldrin was also detected in the ditch systems. OCPs were also detected throughout the Section 1 ditch system at concentrations exceeding 1.0 ug/g. The presence of compounds in the ditches and overflow basin west of Lake Mary demonstrates the intensity of sediment delivery throughout the ditch systems. This source is the receiving ditch system from Lake Ladora overflow and extends several thousand feet prior to its termination at an earthen dike. OCPs in the ditch and overflow basin were detected at concentrations slightly below those in Lake Ladora.

Surface waters from the Section 1 and 2 ditch systems also contained the greatest abundance and highest concentration of OCPs. This suggests that these ditches act as prominent migration pathways. OCPs were detected in WBZ 1A-1 wells, both upgradient (Well 02020) and downgradient (Well 02037) of the section of the Sand Creek Lateral where they were detected in the sediments. Therefore, no obvious connection exists between the OCPs detected in the Sand

Creek Lateral and those detected in the groundwater. However, the OCPs were detected in deep sediments in the Sand Creek Lateral and VHOs were detected in both the surface water in the lateral and in groundwater below the lateral, which could indicate a possible pathway to the groundwater.

In SSA 3, OCPs were detected only in buried lake sediments in Section 12, not in Section 11 buried lake sediments. Based upon RI results, the OCPs are confined to the assumed boundaries of the Section 12 sediments, and are unlikely to migrate to other media or locations. Dieldrin is the most commonly detected analyte in these soils, followed by aldrin and DDE. Distribution of OCPs is widespread and occurs at depths exceeding 5 ft. The highest concentrations of OCPs occur in the 2 to 5 ft interval, presumably because of the potentially contaminated sediments being buried under clean material. OCPs were detected in the 0 to 1 ft interval, however, perhaps as a result of the action of burrowing animals present on the site, or due to unforeseen mixing of subsurface materials with clean topsoil during burial. The contamination at this source area tends to be concentrated near and within the bisect ditch that separates the sources into two parts. OCPs detected within the bisect ditch are most likely associated with sediments deposited through surface water overflow from Upper Derby Lake, rather than a lateral subsurface migration of OCPs from the buried sediments into the watercourse. OCPs were not detected in any well downgradient of the Section 12 sediments.

Although OCPs were not detected in Section 11 buried sediments during the RI program, historical evidence suggests that since the lakes contained these compounds, the sediments would also contain the same compounds. It is possible that analytical methods utilizing lower detection limits could detect the presence of OCPs at this potential source.

In SSA 4 several OCPs were detected during the RI program in the Section 1 trash dump. No particular OCP analyte was dominant at this site. Although OCPs were detected at all depth intervals, contamination tended to be highest in the 0 to 2 ft intervals. Because most OCP detections occurred in surface intervals, possible migration pathways for these analytes include eolian dispersion and surface run-off to adjacent depressions. Run-off and rain

splash erosion transport tend to be restricted to short distances. Since the predominant direction of wind at RMA is from the south, suspension and transport of particles potentially contaminated with OCPs would be expected into adjacent areas of Section 1 investigated under the RI. Surface water in ditches does not come in direct contact with the trash dump; however, OCPs have been noted west of the dump in a process water ditch. Groundwater does not contain detectable OCPs in the vicinity of the trash dump, and no migration pathways are evident.

In SSA 5 relatively few OCPs were detected in soils, sediments, surface water and groundwater. Low concentrations of OCPs were detected in Section 1 soils adjacent to the trash dump, and appear to be influenced by rain splash or surface water runoff from that area. Other spurious detections of OCPs were associated with surface water drainage in the Havana Ponds areas, presumably originating from the Peoria Ditch. Low concentrations of OCPs were detected in surface water along the southern border of RMA. Confirmation of the presence of OCPs in ditch sediments is unknown, since sampling was not conducted in these areas. In this case, surface water is clearly a primary migration pathway, but the extent of lateral transport to other media is unknown. An isolated detection of OCPs below a concentration of 1.0 mg/l occurred in surface water in the Havana Ponds. OCPs were not evident in nearby soil samples.

#### 3.3.8.2 Potential OCP Receptors

Downstream soils, sediments, and biota are the potential receptors of OCPs in the SSA. If process water and runoff drainage continue to carry sediments from South Plants, additional contributions of OCPs will continue to migrate to the lakes. The most probable downstream receptors are the Section 1 and 2 ditches (including Sand Creek Lateral) and Lower Derby Lake. Lesser effects are anticipated in Upper Derby Lake, Lake Ladora, Lake Mary, Eastern Upper Derby Lake, and Rod and Gun Club Pond due to their increased distance from the ditch systems and their present hydrologic characteristics.

The OCPs of concern to biota in the SSA (aldrin, dieldrin, chlordane, DDE, DDT, and isodrin) tend to be highly toxic and bioaccumulative. The OCPs

produce both acute and chronic effects on terrestrial and aquatic organisms and are highly bioaccumulative (USEPA, 1980c; Anderson & DeFoe, 1980; USEPA, 1979). The major exposure pathways are ingestion of surface water, soil, or food items. The OCPs are believed to cross over from the abiotic to biotic communities through absorption by rooted aquatic plants, ultimately leading to accumulation by herbivorous and carnivorous fish, waterfowl and raptors (Rosenlund, et al., 1986). High turbidity in Lower Derby Lake may cause suspended sediments to contact bottom feeding fish as well. Annual decomposition of aquatic organisms serves as a future source of sediment contamination. Biota other than plants are not expected to contact groundwater on a regular basis. Because of the tendency of the OCPs to bioaccumulate in tissue, organisms at the top of a food chain are at greater risk of adverse effects than organisms at a lower trophic level.

#### 3.3.9 Arsenic

Arsenic was detected in SSA soils and lake sediments. It was also detected in surface water from ditches and the overflow basin west of Lake Mary. Arsenic was detected in groundwater samples more than any other metal. It was detected in a very small number of samples from wells screened in all water bearing zones both north and south of the lakes. These detections were never replicated despite multiple sampling in nearly all of the wells. Arsenic was also present in lower trophic level aquatic organisms. Despite the occurrence of arsenic in several media, naturally occurring background concentrations of this metal complicate evaluations of source contributions and migration pathways.

Arsenic is a naturally occurring metal, which is found in a number of oxidation states. Mobility and toxicity of this element are dependent upon its ionic speciation, which is controlled by external variables such as Eh-pH and media characteristics. The arsenate (+5) and arsenite (+3) species are commonly found in moderately reducing systems such as the lakes and ditch sediments. As evidenced by its distribution in the lakes, the majority of arsenic detections are found in reducing systems in the SSA. As with other metals, the amount of clay minerals present in soils tend to control arsenic movement through adsorption processes. If present in fine sediments, arsenic

may be carried downstream via fluvial processes or distributed by eolian transport.

#### 3.3.9.1 Arsenic Migration Pathways

The affinity of arsenate and arsenite for the fine sediment fraction suggests that eolian and surface water transport could be significant migration pathways for arsenic at RMA. The presence of arsenic in lakes, ditches, and ponds in the SSA is markedly less widespread than organic compounds. Arsenic was primarily detected in soils at concentrations within its reported indicator range; however, it was detected at concentrations exceeding its indicator range in the southwest portion of Upper Derby Lake (13 ug/g), in Lake Ladora (16 ug/g), and in the Section 3 overflow basin (14 ug/g).

Based upon the lack of arsenic detections in Lower Derby Lake, its entry into Lake Ladora may have been directly from runoff from the western portion of South Plants, via the Sand Creek Lateral. The presence of arsenic at elevated concentrations in the southeast portion of Upper Derby Lake suggests that arsenic may have entered the sources via the Highline Lateral or Uvalda Ditch. A surface water sample from the Uvalda Ditch did contain elevated concentrations of arsenic. Arsenic is bound to organic matter and silty clay sediments in the lakes, preventing substantive lateral or vertical migration.

Although arsenic was detected in sediments from Lake Ladora and Lake Mary, it was not detected in surface waters of these lakes or in Lower Derby Lake and Rod and Gun Club Pond. Surface water data are not available for the other source area lakes. Arsenic was detected, however, in groundwater wells downgradient from Lake Mary (Well 03006 and 03007). The soil and groundwater data are not conclusive as to which lakes, if any, are acting as sources of arsenic contamination. Groundwater data are not available for the other source area lakes.

Like DBCP, the presence of arsenic in soils of the ditch systems (SSA 2) is sparse, occurring sporadically and at concentrations within its indicator range. Its greatest abundance occurs in the Sand Creek Lateral portion of the Section 2 ditches near Lake Ladora (all below 10 ug/g) and in the overflow basin west of Lake Mary (over 10 ug/g).

Naturally occurring arsenic is ubiquitous in soils, alluvium, and bedrock at RMA. Bedrock tends to contain slightly elevated arsenic levels relative to overlying soils. This is especially true in soils containing permeable sands, such as those within and near the overflow basin. The fine grained layers of the Denver Formation, as well as associated lignitic lenses, may host naturally high concentrations of arsenic. Although the CRL to 10 ug/g range is considered reasonable for determining naturally occurring arsenic, areas of naturally elevated concentrations may occur. Percolation of water containing arsenic through the vadose zone may occur if sufficient force is provided to leach the analyte at low concentrations. However, the limited number of groundwater detections in this area is difficult to attribute to an SSA source and more likely representative of natural conditions.

Arsenic was detected in the unconfined water bearing zone (WBZ 1A-1) only in Well 01024 (1 of 3 samples), downgradient of Lower Derby Lake; and Well 01021 (1 of 4 samples), potentially downgradient of Upper Derby Lake when it contains water in its upper reaches. Arsenic was not detected in any WBZ 1A-1 wells downgradient of Lakes Ladora and Mary. This is weak evidence that arsenic in the groundwater is related to the sediments in Upper Derby Lake.

Arsenic was detected in the Denver Formation WBZ 2 in Well 01022 (1 of 4 samples) located in a cluster with 01021 which is probably downgradient of Upper Derby Lake but is under confined conditions. The only other detection of arsenic in this water bearing zone was in Well 02035 (1 out of 3 samples), which is not downgradient of any of the lakes.

Arsenic was detected in WBZ 3-4 in downgradient of Lower Derby Lake and Lake Mary, but these wells are also screened in confined zones.

Given the random dispersion of arsenic hits, the nonrepeatability of hits, the fact that most of the hits are in lower confined aquifers and that arsenic is ubiquitous in groundwater, the relation to surface sources, including the lakes, is extremely unlikely.



### 3.3.9.2 Potential Arsenic Receptors

Potential arsenic receptors in the SSA are downgradient groundwater, sediments, and biota. Most arsenic concentrations detected in groundwater occurred within a range attributable to natural occurrences. The typical range for arsenic in natural waters is 1.0 to 30 ug/l (Dragun, J., 1988). The levels of arsenic found in soils and sediments appear moderately bound to the sediments, preventing it from becoming available to aquatic biota. Arsenic can concentrate to some extent in aquatic ecosystems and can cause harm to aquatic organisms at sufficient concentrations (USEPA, 1985; Gilderhus, 1966). Little bioaccumulation is expected in terrestrial ecosystems. Plants do not concentrate arsenic; therefore, a food ingestion pathway is not anticipated. In the SSA, arsenic has concentrated in plankton and macrophytes but has not accumulated up the many trophic levels found in aquatic systems. The presence of arsenic in Lake Mary aquatic systems may be due in part to residual metals remaining from the sodium arsenite treatment in 1962. This treatment was intended to control aquatic vegetation (RMA 1962a; RMA, 1962b).

### 3.3.10 Mercury

Mercury was detected in shallow and deep soil and sediment samples from the SSA. No detections of mercury were noted in surface water, while it was detected in Upper Denver Formation Well (02037) and deeper Denver Formation groundwater wells (Wells 01032, 02035, 01023, and 02012) in the vicinity of SSA source areas and the boundary with the SPSA.

The behavior of mercury in aqueous and solid systems is dependent upon Eh-pH characteristics and physico-chemical balance of the prevailing media in which it occurs. In the SSA, the mercuric (+2) species tends to predominate most oxygenated soil and surface water environments, as well as in moderately oxygenated alluvial groundwater. If moderately reducing groundwater conditions are present in the Denver Formation aquifers, mercurous and elemental forms of mercury may exist. The solubility of inorganic mercury in oxidation states is low, and as a result, mercury in soil is considered relatively immobile. Leaching from soil and sediment will be minimal, and retardation in groundwater will be high. Solubility and subsequent transport in the dissolved phase may be significantly enhanced by the presence of dissolved organic carbon or by conversion to organic forms.

Sorption of mercury is dependent on the organic carbon content and grain size of the soil or sediment. Natural occurrences of organic matter in lake sediments have been found quite effective in binding mercury and preventing dissolution into water (Gambrell et al., 1978). Feick and others (1972) reported that partitioning of mercury between sediments and waters is four times greater in organic-rich sediments than in low-organic sediments. Gibbs (1973) has studied the effects of organic matter in controlling the behavior of mercury, and other studies have verified the effects of larger surface area and cation exchange capacity as key elements in affecting the adsorptive potential of organic matter (Jonasson, 1977). Current pH and texture conditions preclude rapid desorption of mercury from sediments. Migration of mercury may occur in the SSA as wind-blown dust or suspended bed load and sediment in surface water.

Mercury can volatilize to the atmosphere from both aquatic and terrestrial environments, particularly when present in elemental and organic forms. Atmospheric transport is considered a major environmental distribution pathway of vaporized mercury. Rates of volatilization are reduced by conversion of elemental mercury to complexed or solid species.

Although mercury uptake by plants has not been demonstrated in the SSA, its presence in large concentrations within the 5 ft root zone may enable plants to bioaccumulate the metal under altered soil pH conditions. Mercury may also be bioaccumulated by numerous aquatic organisms. Appreciable bioconcentration or biomagnification of mercury can occur in biota.

#### 3.3.10.1 Mercury Migration Pathways

Surface water transport of sediments and eolian transport are potential migration pathways for mercury. Although mercury naturally occurs at very low concentrations, most detectable levels of the element occur in association with source areas in the SSA. Mercury was detected throughout the 0 to 2 and 2 to 5 ft intervals of two SSA 1 sources, Upper and Lower Derby Lakes and Lake Ladora. In the surface interval, mercury was detected above 1.0 ug/g (over ten times above the upper end of its indicator range) near and in the inlets and outlets to Upper and Lower Derby Lakes, respectively. In addition, in

Lower Derby Lake, mercury was detected in the deepest portions of the lake in a similar pattern to that of DBCP. These areas also correspond to the higher points of organic matter probably contributing to the high retention of this metal. Several studies have shown that as aquatic organic matter increases, overall sediment grain size decreases and active surface area increase. Correspondingly, increased surface area tends to increase the ability to concentrate metals, including mercury (Horowitz, 1985). In Lake Ladora, mercury was detected throughout organic surface sediments at concentrations exceeding 0.1 ug/g.

The distribution of mercury in Upper and Lower Derby Lakes suggests that run-off from South Plants soils containing detectable concentrations of mercury has occurred and probably continued occurring during the post-dredging years. In fact, the highest years of mercury contamination in Lower Derby Lake and Lake Ladora ranged from 1962 to close to 1969 (Bergerson, et al., 1984). This run-off was transported via the ditch systems and appears to be concentrating in deeper areas of the lakes where sediments have a propensity to accumulate. Additionally, presence of this element at concentrations above its indicator range in the adjacent Sand Creek Lateral and lack of detection in the inlet channel to Lake Ladora from Lower Derby Lake indicate that South Plants run-off may have contributed to the high levels of mercury in Lake Ladora. On one occasion, mercury was detected above its indicator range below a depth of 2 ft. High percentages of clays, moderate organic carbon content, and high electrical conductivities in surface sediments are edaphic factors that may have resulted in dramatic reductions of mercury detections with depth in all lakes, particularly in Lake Ladora.

Mercury was not detected in the surface waters of Lower Derby Lake or Lake Ladora. Although mercury has flowed through surface water systems, it is apparent that mercury has partitioned onto solid sediment particles through adsorption onto silt/clay complexes and organic matter. Rubin (1976) reported that when mercury was introduced into aqueous systems, suspended sediments containing inorganic and organic sorbates remove a major portion of the element. The study by the USFWS (Bergerson, et al., 1984) confirmed that in all lakes studied, mercury content in suspended sediments dropped dramatically

over a relatively short period of time. This probably contributes to the relatively few detections of this metal as a function of distance from the primary sources (in South Plants). The rate of removal is a function of redox conditions, total suspended solids, recharge discharge rates, and the textural and mineralogical nature of the suspended particles. In addition, mercury may also have been readily adsorbed by accumulated organic matter, which may explain its presence in large concentrations in the inlet channel of Lake Ladora.

As in the lakes, mercury contamination was found to be widespread in SSA 2 source ditches. Mercury occurred most often in the 0 to 2 ft intervals. The element was detected at its highest concentrations (ten or more times above its indicator range) in the ditch leading west from Lake Mary, and in the Section 3 overflow basin. The Section 1 ditch system contains similarly high concentrations of mercury, upstream from where the element was detected in the sediments of Upper and Lower Derby Lakes. The presence of mercury in the ditches and overflow basins underscores the correlation between these sites and the lakes. The mercury detections were far above the water table beneath the Sand Creek Lateral and the overflow basin, but may be near or at the water table under the Section 1 ditches near the SSA boundary. However, samples from wells downgradient of this area have not had mercury detected.

In SSA 3, mercury was detected above its indicator range in buried sediments from both Sections 11 and 12. The element was detected more frequently and at concentrations well above its indicator range in Section 12 sediments, although concentrations of this element were also above its indicator range in Section 11 sediments. At both sites, mercury was detected most often in the 2 to 5 ft interval and the 5 to 20 ft interval. The concentrations at which mercury was detected correspond to the similarly high concentrations found in the sediments in Lake Ladora, Lower Derby Lake, and Upper Derby Lake. Both of the Sections 11 and 12 buried sediments had mercury within the 5 to 20 ft interval, which may be in contact with the water table in this area. However, mercury was not detected in the water table aquifer downgradient of these two sites.

In SSA 4, mercury was not detected above 0.1 ug/g in any location. It was not detected in nearby surface soils outside potential source boundaries nor in hydrologically connected surface water. The lack of mercury within levels of concern or in nearby surface or groundwater systems indicates that there are no potential pathways for mercury from this subarea.

Mercury was detected in soil samples from a location north of the trash dump (Site 1-12). Other contaminants have also been found at this location and it has been designated as a new site. The origin of the contaminants is unknown, but because it is located near a road on the way to a disposal site, the contaminants may have been from a spill, the intentional dumping of wastes, or due to runoff from the trash dump. The other detection of mercury was in surface soils near Upper Derby Lake. The source of this contaminant may be the sediments in Upper Derby Lake, as the lake is usually dry.

Mercury was not detected in any surface water samples collected from the SSA during the RI or during previous studies. Surface water does not appear to be an active pathway for the metal at this time, though the presence of mercury in the ditch and lake sediments indicates that surface water was an active pathway in the past.

Eolian transport is also a possible pathway for mercury sorbed to soils and sediments. Mercury was detected in the surface interval at many sites in the SSA, including the ditches, dredge piles, and Upper Derby Lake, which is often dry. Although healthy vegetative cover minimizes the effects of windblown dust, wind could still carry mercury-contaminated soils from these sites into the rest of the SSA and neighboring areas. However, air monitoring conducted in the SSA did not detect mercury, nor is mercury found outside of source areas, with the exception of two detections near Upper Derby Lake. One of these detections extended below 5 ft in depth and is not related to eolian transport.

Groundwater also does not appear to be an active pathway for mercury though the metal has been detected in various wells. None of the mercury detections in the wells appears to be related to the soil/sediment detections in the

SSA. Mercury was only detected in five samples from various water bearing zones, both north and south of the lakes. Four of the five detections were from samples collected during one sampling period. Mercury detections in groundwater occur in WBZ 1 on the northwest side of the SSA; in WBZ 2 in the northeast corner and near the center of Section 2; in WBZ 3 immediately north of the Section 12 dredged sediment pile; and in the southeast corner of Section 2, downgradient of the Section 11 dredged sediment pile. The mercury detection near and downgradient of the dredged sediment piles does not appear related to the piles because they are in lower Denver water bearing zones, which appear isolated from the surface and water bearing zones above them.

#### 3.3.10.2 Potential Mercury Receptors

The most prominent receptors of mercury in the SSA are downstream sediments and terrestrial and aquatic biota. Mercury may be present in downstream surface waters for short periods, but by its chemical and physical nature, would be expected to settle rapidly in resident sediments. Although relatively insoluble in water, mercury sorbs with great affinity to mineral and organic surfaces in settled and suspended sediments (Thibodeaux, 1979).

Some mercury may remain in solution, where it can be absorbed by fish, plankton, and aquatic macrophytes. Where mercury is present in surface soils or exposed sediments, high exposure potential exists for bioaccumulation in successive biological species along aquatic food chains. Little accumulation is expected in terrestrial systems. Historical investigations in Lakes Ladora and Mary from 1977 through 1982 found that concentrations of mercury in fish repeatedly exceeded Food and Drug Administration limits of 0.3 ug/g (Thorne, 1982). Mercury levels in biota continue to be elevated. Even though mercury was not detected in surface water, it has been found in surface sediments, and is likely to be found in aquatic organisms due to the high bioaccumulation potential of this metal. This contamination will probably continue since aquatic plants are capable of absorbing mercury in sediments containing less than 1.0 ug/g (Rosenlund, 1986). Several organisms containing potential contaminants in tissues have been collected from lakes in the SSA where mercury concentrations in water are below detection limits. This suggests that most of the exposure to mercury comes from contact with rooted aquatic

plants, detritus, and sediments. Bioconcentration factors for aquatic organisms are large. Potential exposure to human receptors is minimal, since local fisherman are required to release all fish caught in the lakes and collection of terrestrial species is restricted.

### 3.3.11 ICP Metals

All five ICP metals (cadmium, chromium, copper, lead, and zinc) were detected repeatedly in SSA soils. All of these metals, except cadmium, were detected in surface waters, primarily in ditches along the southern boundary of the SSA. All five metals were detected in alluvial and Denver Formation groundwater.

ICP metals occur as minor components of natural soils and sediments. Concentrations greater than anticipated natural levels of ICP metals in surficial soil, sediments, or water may be attributed to iron-manganese oxide cements or concretions, lignitic or carbonate-rich layers, fine grained sediments, or detrital accumulations of heavy mineral grains in fluvial deposits. Their presence in the dissolved phase is also a common natural parameter of surface and groundwater. Defining sources and pathways for ICP metals is a complex task that cannot produce completely definitive results due to their pervasive natural occurrence. The following discussion describes the behavioral characteristics of these analytes in various environments and their relative concentrations in SSA soils, air, and groundwater. For the purpose of this discussion, only concentrations above soil indicator ranges for these metals are included.

Four of the five ICP metals, cadmium, copper, lead, and zinc, behave similarly in the environment. Although their specific behaviors are strongly related to the chemical environment of interest, numerous generalizations may be made for the analytes in this group. Cadmium, copper, lead, and zinc occur in the divalent state under Eh-pH conditions encountered at RMA. Although solubilities of these metals vary widely under commonly encountered environmental conditions, their aqueous mobility is limited by sorption to mineral and organic solids. They exhibit strong affinity for iron and manganese oxyhydroxides, organic matter, carbonates, and clays. As a result,

they are generally associated with and travel substantial distances in fine grained soil or sediment (Horowitz, 1985) rather than the surface or groundwater media.

Leaching of cadmium, copper, lead, or zinc from soils in the saturated or vadose zone is difficult due to the abundance of sorptive solids, particularly in soils having a pH equal to or greater than 7.0 units. Partitioning measurements indicate an increasing affinity for the solid phase in the following order: Cadmium < Zinc < Copper < Lead (Dragun, 1988). Studies of cadmium solubility have found a 100-fold increase in sorption for each unit increase in pH (USEPA, 1983). Although cadmium is the most mobile of this group of metals, it is also relatively difficult to leach from soils. Adsorbed metals may be remobilized following complexation with dissolved organics such as humic and fulvic acids.

A fifth ICP metal, chromium, occurs in two oxidation states in natural systems. The hexavalent state ( $\text{Cr}_2\text{O}_7^{2-}$ ,  $\text{CrO}_4^{2-}$ ) is thermodynamically stable in well oxygenated waters. The anionic hexavalent species are moderately soluble and weakly adsorbed, resulting in considerable environmental mobility in surface and groundwater. Hexavalent chromium is also the more toxic form of the metal. This migration pathway is probably responsible for the fairly common occurrence of detectable chromium in several alluvial wells throughout the SSA. Chromium contained in chemical manufacturing wastes is generally in the hexavalent state. Most naturally occurring chromium exists in the trivalent state ( $\text{Cr}^{3+}$ ,  $\text{CrO}_4^{2-}$ ). Where present in minerals, it is mobilized to different degrees depending on the solubility of the mineral in which it is contained.

Copper and zinc are incorporated by plants and animals as essential nutrients and are bioconcentrated even at naturally occurring concentrations, but generally not biomagnified. Copper shows its most adverse effects on aquatic plants, invertebrates and fish. Effects on aquatic organisms are widely variable (Demayo & Taylor, 1981), but copper is usually more harmful to freshwater fish than any of the other heavy metals (Moore & Ramamoorthy, 1984b). Generally, the species and size of aquatic organisms determines the



harmful threshold of zinc (Taylor et al., 1982; Warnick & Bell, 1969). Copper and zinc may have synergistic effects on each other. Lead has similarly been shown to bioconcentrate in a variety of organisms; although microcosm studies indicate that it is not biomagnified through the food chain. Lead is most harmful in a dissolved form. Cadmium is readily concentrated in plants and aquatic organisms, bioconcentration factors suggest that appreciable bioconcentration and biomagnification of cadmium may occur. Chromium absorbed by certain plants tends to remain primarily in the roots and is poorly translocated to the leaves. Bioconcentration factors for chromium indicate a moderate potential for bioconcentration, but much lower than that for either mercury or cadmium. Chromium is rapidly eliminated from higher organisms, suggesting little potential for biomagnification. Uptake in areas of high metal concentrations is likely, considering the affinity of metals for shallow soils and sediments.

Chemical characteristics of the water are important factors affecting impacts of metals on biota. Alkalinity, hardness, pH, dissolved oxygen level, and temperature control adverse impacts in aquatic systems (McKee & Wolf, 1963; Demayo et al., 1981; 1982).

#### 3.3.11.1 ICP Metal Migration Pathways

Surface water transport of sediments, groundwater movement, and eolian transport are potential migration pathways for ICP metals. In soils, concentrations of ICP metals exceeding their indicator ranges occur in the lakes (SSA 1), ditches (SSA 2), and at isolated locations in the balance of areas investigated (SSA 5). In most cases, elevated concentrations of ICP metals in surface soils exhibit limited downward migration through the soil column. In Upper Derby Lake, elevated levels of zinc and lead were confined to the 0 to 2 ft intervals. Detection of high metals in this area roughly corresponds to high arsenic detections. Soil reaction ranges from moderately acid to neutral in this area, while textures range from organic clayey silts to silty sands. Organic matter content exceeds one percent in surface soils. Few high detections of copper were reported in Upper Derby Lake, while Lower Derby Lake and Lake Ladora reported more detections of copper above its indicator range. All reported high detections occurred in surface intervals.

Several copper sulfate treatments to control algal growth were undertaken over the years in the lakes (Acumenics, 1988). It is possible that residual copper from the dissolution of these treatment salts has been retained in surface organic layers. Eastern Upper Derby Lake, Lake Mary, and Rod and Gun Club Pond did not contain elevated concentrations of ICP metals. An anomalously high concentration of chromium (150 ug/g) was detected in approximately the lowest portion of Lower Derby Lake and slightly above its indicator range in Lake Ladora. Cadmium was not found above its indicator range in SSA 1.

ICP metals were not detected in any of the surface water samples collected from the lakes during the RI or during previous investigations.

ICP metals occur at their highest concentrations in SSA 2 soils, ditches, and overflow basins. Lead, zinc, copper, and chromium were all detected above their indicator ranges, primarily in the Sand Creek Lateral. In all cases, the metals were detected at their highest concentrations in the 0 to 2 ft intervals. At one location in the Sand Creek Lateral, east of Lake Ladora, an anomalous level of lead was detected in the surface sediments, east of Lake Ladora, at concentrations ranging from 150 to 1200 ug/g. Zinc was also detected in this area at concentrations up to 160 ug/g. Elevated lead, zinc, and copper were detected throughout surface and subsurface soils in the remainder of the Sand Creek Lateral, north to December 7th Avenue. Surface water in the ditches did not contain detectable levels of ICP metals. Furthermore, vegetation is abundant in the Sand Creek Lateral, increasing the potential for root zone absorption. Silts and clays are also abundant, increasing the adsorptive surface area and attenuating metals in either suspended or settled sediments. Although not present in surface water, sediments entrained in flowing natural waters may transport directly into the lakes or flow north in the Sand Creek Lateral toward the North Central Study Area.

Elevated concentrations of lead exceeding its indicator range were detected in soils and sediments at isolated locations in SSA 5, specifically in Section 12. Migration pathways are limited to shallow infiltration, minor surface transport by wind, or storm water runoff. Samples in which lead above its

indicator range was detected also contained high percentages of clay. Elevated concentrations of lead in clayey soils and singular detections over its indicator range may represent natural distributions of this metal. Along the southern boundary of RMA, in Sections 7, 11, and 12, surface water samples in drainage ditches and the Havana Street Interceptor Ponds contained highly elevated ICP metals. Surface water discharge from off-post areas is another likely source of high metals in this area.

Analytical data from air quality monitoring stations AQ5 and AQ6 indicate that wind transport provides a significant pathway for transport and dispersion of ICP metals (particularly copper and lead) from on-post and off-post areas. The limited number of elevated concentrations in soils indicates that the majority of metals transported by eolian processes are natural components of surface soil. Seasonal sanding of East 56th Avenue and Havana Streets may contribute a component of eolian material as well. Since the primary wind directions during metals sampling in the SSA were from the southeast, south and southwest, it is reasonable to assume that dust generated from nearby traffic is one likely source of airborne metals in this area. Dry fallout and rainout of particulate lead from urban air pollution is also a migration pathway for this metal. Rain or snow washout and subsequent transport through surface water complete this process.

Groundwater does not appear to be a significant pathway for ICP metals in the SSA. Groundwater analytical data for metals do not indicate elevated concentrations as found in soils in some locations in the SSA. However, low concentrations of cadmium, zinc, copper, lead, and chromium were found throughout groundwater in the SSA, and these may be naturally occurring constituents. Cadmium was only detected once in Well 07001, upgradient of any of the processing and disposal areas. This same well also contained chromium, copper, lead, and zinc and was the only well in which all of these analytes were detected. These detections were not repeated despite additional sampling. The only other detection of cadmium was in a WBZ 4 well (01048) in the northeast corner of the SSA. Conversely, zinc was detected in nearly every well sampled in the SSA, though the metal was detected at higher concentrations north of the lakes, downgradient from the SPSA. The difference

in zinc concentrations may be due to the aquifer material. The higher zinc concentrations were found in WBZ 1 wells, as opposed to WBZ 1A wells with the exception of Well 02020, which lies at the edge of the area of unsaturated alluvium north of Lake Ladora, and Well 01024, which is immediately downgradient of Lower Derby Lake. Lead was only detected in four out of 42 wells sampled at low levels in all water bearing zones and copper was detected only in WBZ 1A wells. Chromium was detected randomly in ten out of 42 wells sampled and was found in all water bearing zones. Most of the detections in the water table aquifer were from wells south of the lakes. Only one detection was replicated by further sampling and this was from a well south of Lower Derby Lake.

#### 3.3.11.2 Potential ICP Metal Receptors

Biota are the primary receptors of ICP metals in the SSA. The major routes of exposure to plants are through plant roots; to wildlife through ingestion of soils and sediments, water, and food items; and to aquatic organisms by contact with surface water and sediments. Many factors affect the ability of plants to absorb metals, including, but not limited to, physical and chemical characteristics of the soils; concentration, mobility, ionic form, and availability of metals in the soils, soil and air temperature, season, plant species, and plant vigor. With regard to soil characteristics, if a metal is weakly sorbed or soluble, it can become available for plant uptake or transport by surface water run-off. The plant-available fraction of soils metals directly affects vegetation response, although the level of total soils metals is fairly linear in relation to the amount available for plant uptake.

Plant species vary widely in their ability to absorb and accumulate metals. Some species can tolerate and concentrate relatively high levels of metals and are termed accumulator species. Chromium and lead have limited uptake in plants and are not readily translocated to edible portions. Cadmium, copper, and zinc are more readily translocated in plants. Cadmium was not often found in SSA soils, sediments, or waters, and is therefore not a contaminant of concern to biota. Copper is an essential element for plants and animals.

Natural variations in copper concentrations in vegetation range from 4 to 15 ug/g (USEPA, 1983). The adverse effects of copper upon aquatic life is inversely hardness dependent (USEPA, 1986d). Invertebrates and fish are equally sensitive toward exposure to high levels of copper (USEPA, 1986). Since most lead appears entrained by mineral and organic surfaces in submerged sediments, exposure to and uptake of lead by biota is negligible. Furthermore, surface water samples and water hardness in the lakes suggest that exposure by aquatic organisms to lead is minimal.

Humans and other animals are potential receptors of airborne lead in the southern boundary area of the SSA. The major source of this compound is presumably off-post exhaust from automobiles. Lead is considered nonessential for both plants and animals (Gough et al., 1979; USEPA, 1983). Normal lead concentrations in plants reported in the literature range from 0.1 to 20 ug/g.

Although zinc is liable to bioconcentrate in aquatic organisms, soil and sediment conditions and water quality in the lakes are not conducive to mobility and uptake of this metal.

ICP metals in groundwater are sporadically distributed in the SSA, and pose no apparent threat to potential receptors.

### 3.4 VOLUME ESTIMATES OF POTENTIAL CONTAMINATION

The discussion of potential contamination in this section is divided into three parts. Volumes of soil associated with analytical detections of contaminants in the Phase I and II RI are estimated and presented first. Other volumes of potentially contaminated soil inferred from historical information and contaminant distribution mechanisms are then discussed. The final part presents estimates of volumes of material in structures in the SSA. Volumes of potentially contaminated aquifer solids were not calculated for the SSA because potential groundwater contaminants are volatile compounds which do not partition significantly to the solid phase within groundwater plumes.

The estimates are intended to summarize the nature and extent of potential contamination in soils, sediments, and structures in the SSA. The estimates do not imply that any or all of the estimated volume of potentially contaminated materials must be remediated, nor do they make any assumptions about the type of remediation that may be required. The estimates do provide a guide to the volume of materials that may be considered in the initial stages of the FS and are subject to change pending the receipt of additional information collected prior to remedial activities.

#### 3.4.1 Potential Soil Contamination Based on Analytical Results

The volume of potentially contaminated soil in portions of the SSA was previously estimated as part of the Decontamination Assessment (RMACCPMT, 1984a/RIC 8403R01) and the Phase I RI. These were estimates of the maximum volume of potential contamination, by any analyte, within the site boundaries established by the Decontamination Assessment. The assumptions for these estimates were conservative, and were intended to establish an upper limit on the volume of potentially contaminated soil.

In comparison, the estimates generated in Section 3.4.1 are intended to be a best judgment of volume of potentially contaminated soil, based upon analytical data from the Phase I and Phase II RI. Estimates were generated separately for each analyte group detected in the SSA. In many cases, a volume of soil contains more than one analyte group, so a total soil volume for the SSA cannot be produced by simply summing volume estimates for individual analyte groups. Total estimates that eliminate overlaps are presented at the end of Section 3.4.1. The following sections include a description of the methodology used to estimate volumes and a discussion of resulting volumes of potentially contaminated soil.

##### 3.4.1.1 Methodology

Soil volumes were estimated by concentration range and depth interval from analyte distribution maps like those found in Section 2 of this report. These maps are not included in Section 3. Depth intervals ranged from 0 to 2, 2 to 5, and 5 to 20 ft. Combinations of simple geometric shapes were used to delineate areas of potential contamination for each interval. Where

necessary, larger scale maps from the Phase I and II RI reports were examined to better define areas or provide more detailed information regarding the detections. These areas, multiplied by an associated thickness, defined the volume of potentially contaminated soil.

A set of assumptions for each type of feature in the SSA was consistently applied to the determination of areal extent and thickness. In general, assumptions were set up to extend potential contamination halfway between detections and clean samples. For a particular sample, this procedure may overestimate or underestimate volumes to a considerable degree. In total, it is a fact that errors in the estimates will balance to produce a best judgment of potentially contaminated soil volume. Similar assumptions were applied to similar features throughout all of the study areas. The assumptions are presented in the following list:

- o Isolated detections within lakes and ponds were assigned an area equal to that of a circle, with a radius equal to the distance to the nearest uncontaminated sample site. Areas including two or more detections were assumed to extend halfway to adjacent uncontaminated sample sites. The mapped borders of the lakes and ponds limited the extent of areas of detections which were not bounded by uncontaminated samples. The assumptions used for detections within the overflow basin and the buried lake sediments were similar to those used for lakes and ponds.
- o The area of potential contamination corresponding to detections within ditches was assumed to have a width equal to that of the ditch plus five ft on each side. The length of the ditch considered potentially contaminated was assumed to extend half the distance to adjacent uncontaminated sample sites, to site boundaries, study area boundaries, or by an amount equal to the distance between sample sites with detections.
- o Assumptions used for the trash dump were similar to those for lakes and ponds, except that the mapped borders of the trash dump did not limit the extent of potential contamination. However, the adjacent road and dam east of the site was assumed to limit the extent of contamination in that direction.
- o Isolated detections outside of the above features were assigned an area equal to that of a circle with a diameter of 20 ft. Areas of two or more detections were assumed to extend halfway to adjacent uncontaminated sample locations.

- o The assumptions utilized to determine the thickness of potential contamination were similar for all source area types. The thickness corresponding to detections in the 0 to 2 ft depth interval was assumed to be equal to the entire interval thickness of two ft. Detections in the 2 to 5 ft interval were assigned the entire interval thickness of 3 ft. The thickness of potential contamination corresponding to detections in the 5 to 20 ft depth interval was assumed to be equal to the difference between the bottom of the 2 to 5 ft depth interval and the water table. The depth to the water table in the vicinity of the source areas in the SSA varies from approximately 10 to 30 ft. The bottoms of lakes and ponds are generally below the water table so the thickness of potential contamination was assumed to be equal to the thickness of sediment (maximum of 5 ft).

#### 3.4.1.2 Estimated Volumes

Nine of the sixteen analyte groups present on the RMA were detected in soils in the SSA. Analyte groups detected include the following:

- o Volatile Halogenated Organics (VHO)
- o Volatile Hydrocarbons (VHC)
- o Volatile Aromatic Organics (VAO)
- o Dibromochloropropane (DBCP)
- o Semivolatile Halogenated Organics (SHO)
- o Organochlorine Pesticides (OCP)
- o Arsenic
- o Mercury
- o ICP Metals

Area and volume estimates of potential soil contamination were prepared for each of these analyte groups with the exception of VHCs and VAOs. An estimate was not prepared for VHCs and VAOs because the number of detections of analytes in this group was limited. These detections occurred in areas containing other analyte groups, so their volumes were effectively included in the volume estimates of potential contamination for the other groups. Unlike surface water and groundwater, OCSs and OPHs were not detected in soils or sediments, therefore, no volume estimates were prepared for these analyte groups.

Despite its potential occurrence in the SSA, methylene chloride was estimated separately from the other VHOs, because this compound is a common laboratory contaminant. Also, the organochlorine pesticides were subdivided into two groups for estimation. The first group, OCP subgroup 1, includes aldrin, dieldrin, endrin, and isodrin. OCP Subgroup 2 includes DDE, DDT and chlordane.



A table, graph, and map are included with the following discussions to present and summarize the estimates for each analyte group considered. The tables summarize area, thickness, and volume estimates. The estimates are tabulated by depth interval and concentration range for each site. The volume numbers on the tables are reported to the nearest two significant figures. Graphs present a visual representation of how area and volume estimates for each depth interval accumulate with analyte concentration. Finally, figures are provided to illustrate the estimated areal extent of potential contamination in the 0 to 5 ft depth zone. The distribution of potential contamination in the 0 to 5 ft zone was judged to be of greater interest and was emphasized with a figure because near surface soils are generally more subject to interactions with other media and potential receptors than deeper intervals. Soils in the 0 to 5 ft depth interval may also be considered separately in the FS, and may require a different remedial approach than deeper intervals. Inclusion of 2 to 5 ft depth in the areal extent illustrations also allows illustration of potential contamination by volatile analytes which are largely absent from the 0 to 2 ft surface interval.

Detections in the overflow basin ditches in Section 3, Upper Derby Lake, and Rod and Gun Club Pond account for the majority of soil potentially contaminated by VHOs. The total volume of potentially contaminated soil is 150,000 cubic yards ( $\text{yd}^3$ ). All but approximately 6,700  $\text{yd}^3$  contained concentrations of less than 1  $\mu\text{g/g}$ . Roughly 80 percent of the potentially contaminated volume of soil occurs in the 0 to 5 ft depth interval (Figures SSA 3.4-1 and SSA 3.4-2; Table SSA 3.4-1).

Volumes of potentially contaminated soil based upon methylene chloride detections totalled 49,000  $\text{yds}^3$ . The methylene chloride detections may possibly be laboratory artifacts, so these were estimated separately from the remaining VHOs (Figures SSA 3.4-3 and 3.4-4; Table SSA 3.4-2). Isolated detections of methylene chloride in a trench and open storage area in Section 2 were estimated laboratory contaminants since the concentrations are low, methylene chloride was the only analyte detected in these two areas, and there is no available historical data to suggest a source for the methylene chloride. No volume was calculated for these two occurrences.

Most of the volume of soil potentially contaminated by DBCP is found in the sediments of Lower Derby Lake. A total of 250,000 yd<sup>3</sup> of potentially contaminated soil is found in the SSA, all in the 0 to 5 ft depth interval and with a concentration of less than 1 ug/g (Figures SSA 3.4-5 and SSA 3.4-6; Table SSA 3.4-3).

The total volume of soil potentially contaminated by SHOs is estimated to be 35,000 yd<sup>3</sup>. Most of the volume occurs in Upper Derby Lake and the Sand Creek Lateral. Potential contamination by SHOs is confined to depths of less than five feet, and to the lowest concentration range of less than 1 ug/g (Figures SSA 3.4-7 and SSA 3.4-8; Table SSA 3.4-4).

OCP Subgroup 1 (aldrin, dieldrin, endrin, and isodrin) was the most widely distributed analyte group in the SSA. The total volume of potentially contaminated soil in this group is 590,000 yd<sup>3</sup>. Approximately 50 percent of the total volume is found in the sediments of Upper and Lower Derby Lakes. The majority of the soil potentially contaminated by OCP Subgroup 1 occurred within the lowest concentration range of less than 1 ug/g (Figures SSA 3.4-9 and SSA 3.4-10; Table SSA 3.4-5).

The distribution of OCP Subgroup 2 (DDE, DDT, and chlordane) is essentially the same as that of Subgroup 1 except that 65 percent of the total potentially contaminated volume of 310,000 yd<sup>3</sup> occurs in Upper and Lower Derby Lakes (Figures SSA 3.4-11 and SSA 3.4-12; Table SSA 3.4-6).

Detections of the inorganic analytes, particularly the ICP metals, may be due to natural occurrences of the analytes. In preparing volume estimates, an attempt was made to distinguish between natural occurrences of inorganic analytes and those resulting from activities conducted in the SSA. Volumes were estimated only for those soils containing metals at concentrations above their indicator ranges.

Soils containing arsenic above its indicator range (10 ug/g) are found mainly in Upper Derby Lake and Lake Ladora. The entire potentially contaminated soil volume of 18,000 yd<sup>3</sup> is in the 0 to 2 ft depth interval and in the lowest

concentration range for which volumes were calculated (Figures SSA 3.4-13 and SSA 3.4-14; Table SSA 3.4-7).

The total volume of soil in the SSA containing mercury above its indicator range (0.1 ug/g) is 520,000 yd<sup>3</sup>. The contamination is widespread, but the majority of mercury was detected in sediments of Upper Derby Lake, Lower Derby Lake, and Lake Ladora. Mercury occurs in every concentration range and depth interval (Figures SSA 3.4-15 and SSA 3.4-16; Table SSA 3.4-8).

The total volume of soil potentially contaminated by the ICP metals is 180,000 yd<sup>3</sup>. The majority of potential contamination lies in the sediments of Lower Derby Lake, Lake Ladora, and buried lake sediments dredged from Lake Ladora (Figures SSA 3.4-17 and SSA 3.4-18; Table SSA 3.4-9). The Range 1 through Range 4 designations for concentration ranges on these illustrations correspond to the four dot sizes and associated ranges of concentration for each metal found on the Section 2 analyte distribution maps for ICP metals in soils.

The following total volume numbers were generated by eliminating overlapping volumes among analyte groups, thereby assuring that the same volume of soil was counted only once in the total estimate. The total volume of soil potentially contaminated by organic analyte groups in the near surface (0 to 5 ft) interval is estimated to be approximately 780,000 yd<sup>3</sup>. The areal extent of this potential contamination for combined organic groups is shown in Figure SSA 3.4-19. A total volume for the SSA of soil potentially contaminated by organic analytes for all depth intervals was estimated to be 940,000 yd<sup>3</sup>. This estimate includes the volume of potential contamination by methylene chloride.

A similar calculation for combined inorganic analyte groups yields a total volume of potential soil contamination in the 0 to 5 ft depth interval of about 480,000 yd<sup>3</sup>. Figure SSA 3.4-20 presents the areal extent of potential contamination corresponding to this estimate. The combined soil volume estimate for inorganic groups at any depth in the SSA is approximately 570,000 yd<sup>3</sup>.

In summary, sediments in Upper and Lower Derby Lakes and Lake Ladora contain the majority of potential contamination in the SSA. Other significant volumes occur in the Sand Creek Lateral, process water ditch system, buried lake sediments, and the trash dump. The other lakes and balance of areas investigated contribute a relatively small fraction of the total volume of potentially contaminated soil. Figure SSA 3.4-21 is a summary figure showing the estimated areal extent of potential contamination based on analytical results for any depth in the SSA.

#### 3.4.2 Potential Soil Contamination Based on Historical Information and Contaminant Distribution Mechanisms

Potentially contaminated soil is inferred within various sites of the SSA based on historical information and contaminant distribution mechanisms. Each of the inferred areas and associated estimates of volume of potentially contaminated soil are discussed below. The areal extent of these inferred areas is indicated on Figure SSA 3.4-21.

Historical sampling data (Myers and Gregg, 1984/RIC 86192R01; Myers et al, 1983/RIC 84086R01) suggest soil contamination is more widespread within the lakes and pond in Sections 1, 2, 6, and 12 than that indicated by Phase I and Phase II RI analyses. It is hypothesized that OCPs and mercury which have been transported to the lakes and pond, have probably dispersed throughout the bottom sediment. Therefore, in addition to volumes calculated in the previous section, soil contamination is inferred to occur in the lake and pond areas up to the high water level. Estimating depths of contamination based on Phase I and II RI data and historical data, and using the inferred areas indicated on Figure SSA 3.4-21, an additional volume of potentially contaminated soil for each of the lakes and pond was estimated. These inferred volumes are 47,000 yd<sup>3</sup> (3 ft depth) in Lake Mary, 120,000 yd<sup>3</sup> (3-4 ft depth) in Lake Ladora, 240,000 yd<sup>3</sup> (5 ft depth) in Lower Derby Lake, 200,000 yd<sup>3</sup> (3-4 ft depth) in Upper and East Upper Derby Lakes, and 74,000 yd<sup>3</sup> (3 ft depth) in the Rod and Gun Club Pond.

Potential soil contamination is also inferred to be present throughout the Havana Streets Ponds based on some low levels of OCPs and VHOs in the soil and

low to moderate levels of OCPs and ICP metals in surface water and groundwater. Though few samples have been collected and analyzed from these ponds, they do form a sink and collect runoff from areas south and west of RMA. The inferred volume of potentially contaminated soil at low concentration levels in the Havana Streets Ponds is estimated to be 150,000 yd<sup>3</sup>, assuming a 5 ft depth of contamination.

Contamination is inferred in portions of the ditches in the SSA. For the ditches in Section 1, this is based on data presented by Myers and others (1983/RIC 84086R01) indicating OCPs and mercury contamination. Using an estimated depth of 10 ft, the volume of soil inferred to be potentially contaminated for these ditches is 22,000 yd<sup>3</sup>. A relatively small portion of the ditch in Section 3 may be contaminated based on detections of mercury at the upper end of the indicator range in ditch sediments near "C" Street. The inferred volume of potentially contaminated soil for this area, using an estimated depth of 5 ft, is 230 yd<sup>3</sup>. The ditch terminating at the Havana Streets Ponds is inferred to be contaminated based on detections of OCP's and VHOs in the soil and sediment of the ponds and detections of OCPs, arsenic, and ICP metals in the surface water of the ditch. Estimating soil contamination to a 5 ft depth, the volume of potentially contaminated soil in the ditch is 5,800 yd<sup>3</sup>.

It is estimated that soil potentially contaminated by OCP Subgroup 1 exists in the buried lake sediments in Section 11. These sediments were dredged from Lake Ladora. Although not detected by Phase I and Phase II investigations, OCPs were detected during a previously conducted investigation by Geraghty and Miller (1982/RIC 81342R06). Because mercury and OCPs occurred together in the lake from which this sediment was dredged, the volume of potential contamination by these groups is inferred to be comparable. Based upon this assumption, the estimated volume of soil potentially contaminated by OCP Subgroup 1 in the buried lake sediments in Section 11 is 48,000 yd<sup>3</sup>. The concentrations of the potential contamination should be low, certainly less than the CRL used during the Phase I RI investigation. A similar volume of soil potentially contaminated by OCP Subgroup 2 is also estimated to be present in the Section 11 buried lake sediments. Since the areal extent of

this contamination overlaps the area associated with analytical mercury detections, it is not indicated as an inferred area on Figure SSA 3.4-21.

Sampling conducted by Dames and Moore (1985/RIC 85218R01) suggest slightly larger areas of contamination for the buried lake sediments of Sections 11 and 12 than were associated with analytical detections from Phase I and II investigations. The additional inferred area in the buried lake sediments of Section 11 is based on a mercury detection from the Dames and Moore study. The estimated volume of potentially contaminated soil for this area is 56,000 yd<sup>3</sup>, assuming a 10 ft depth. The inferred area in the buried lake sediments of Section 12 is based on an OCP detection. The estimated volume of potentially contaminated soil for this area is 23,000 yd<sup>3</sup>, assuming a 5 ft depth to the north and a 10 ft depth to the south.

#### 3.4.3 Estimated Volume of Structural Materials

Estimates have been tabulated from the Task 24 Structures RI (Ebasco, 1988s/RIC 88306R02) of volume of potentially contaminated material in structures in the SSA. Structures were classified as to suspected degree of contamination based on use history. No structures in the SSA are suspected to be contaminated. Structures suspected to be contaminated by cleanable contain 1,900 yds<sup>3</sup> of material. About 1,800 yds<sup>3</sup> of material are found in the structures suspected to be uncontaminated. Based on visual observation, a total volume of asbestos, estimated to be 24 yds<sup>3</sup>, is also found in structures in the SSA.

Materials in SSA structures, specifically, have not been subdivided by type. However, estimates of types of construction material for the Arsenal as a whole were made in the structures RI. Of the total volume of structural materials, 74 percent is estimated to be concrete, brick or structural steel; 4 percent is wood; 2 percent is material containing asbestos; and 20 percent is tile, piping, minor equipment, nonstructural steel, and miscellaneous other building material.

### 3.5 MASS FLOW RATE OF POTENTIALLY CONTAMINATED GROUNDWATER

A requirement of the SARs is to estimate the contaminant mass flow rate within groundwater in each study area. These estimates are performed across selected cross-sections of plumes for two individual analytes in the SSA and are presented in this section. The estimates are based on data collected during the RI and from data collected by MKE. These data are discussed in Section 2.0.

The estimates do not imply that any or all of the estimated mass of potentially contaminated groundwater must be remediated, nor does it make any assumptions about the type of remediation that may be required. The estimates do provide a guide to the rate of potentially contaminated groundwater flow to be considered in the FS, and are subject to change pending the receipt of additional information collected prior to remedial activities. The following sections include a description of the methodology used to estimate volumes and a discussion of resulting groundwater contaminant mass flow rates for the SSA.

#### 3.5.1 Methodology and Assumptions

Contaminant mass flow rate (M) is defined as that quantity of mass flowing through a given cross-sectional area (A) within a unit of time. Units used in this report are grams per day (gm/day).

Reliable calculation of contaminant mass flow rates in groundwater requires complete and accurate information about various aquifer and contaminant-plume characteristics, including hydraulic conductivity, hydraulic head, effective porosity, hydrodynamic dispersion coefficients, and contaminant concentration. Generally, an understanding of three-dimensional variations in those characteristics is needed. At RMA, many of the required aquifer and contaminant-plume characteristics are presented at a level sufficient for RI purposes, but not sufficient for highly accurate calculations to be made. Nevertheless, preliminary estimates of contaminant mass flow rate are included in this report in order to provide initial estimates of the rate of contaminant movement and to compare estimates across study area boundaries. In order to generate these estimates the following assumptions were made:

- 1) Cross-sections selected for calculation of mass flow rate are drawn perpendicular to the principal direction of contaminant plume migration;
- 2) Steady-state flow occurs in the saturated part of the aquifer.
- 3) Hydraulic communication with underlying formations is neglected unless evidence is available to quantify the effects of communication;
- 4) Contaminant concentrations are uniform throughout the vertical extent of the unconfined flow system at the location of the cross-section;
- 5) The largest value of contaminant concentration between two contours of equal value is assumed to be the value of the nearest data point contained within the two contours. The maximum concentration is assumed to be located equidistant between the two contours;
- 6) Hydraulic conductivity is homogeneous and isotropic. If adequate information is available to justify varying hydraulic conductivity along a cross-section, that information is used;
- 7) Groundwater flow is linear. In other words, potentiometric-surface contours are parallel to the cross-section;
- 8) Unless adequate data are available to justify varying the hydraulic gradient along a cross-section, the hydraulic gradient is assumed to be uniform;
- 9) Hydrodynamic dispersion is negligible. Effects of dispersion generally are greatest in the vicinity of large concentration gradients. However, the magnitude of dispersive mass flux generally is small when compared to advective mass flow. Given the uncertainty inherent in the flow rate estimates due to potential variations in hydraulic conductivity and other aquifer characteristics, the effects of hydrodynamic dispersion are considered to be minor.

The selection of analyte groups or individual contaminants to be used in calculating mass flow rates depends on the availability of data, sufficient in spatial distribution and consistency, to permit contouring a contaminant plume. Contaminants selected for the SSA are benzene, VHOs, and VHCs.

### 3.5.2 Contaminant Mass Flow Rate

Calculation of mass flow rate for a selected contaminant is accomplished by dividing the selected cross-section into a number of variable-width segments. The lateral width of each segment is typically delimited by vertical concentration maxima or minima. Additional segments may be justified to account for variations in hydraulic conductivity or hydraulic gradient along the cross-section. Within each segment, average values of hydraulic



conductivity, hydraulic gradient, saturated thickness, and contaminant concentration are determined. Unless otherwise stated, average values are obtained by linear approximation between segment-boundary values.

Contaminant mass flow rate for each segment is calculated by the expression for advective mass transport per unit time.

$$\text{Mass/time} = Q \times c = k i c w b$$

where  $Q$  is groundwater discharge across a given cross sectional area  
 $c$  is contaminant concentration (mass/volume)  
 $w$  is segment width  
 $b$  is saturated thickness  
 $k$  is hydraulic conductivity (length/time)  
 $i$  is hydraulic gradient (ft/ft)

The mass flow rate is equal to the discharge of fluid through a cross-sectional area times the concentration of the substances of interest in the fluid. Total mass flow rate of a contaminant for the cross-section is obtained by summation. Contaminant mass flux is obtained by dividing total mass flow rate by total cross-sectional area.

The only groundwater contaminants in the SSA with sufficient data to permit contouring are VHOs, VHCs, and benzene. Mass flow rate values were derived only for these contaminants. The groundwater data used to construct the plume maps for these contaminants are from the third quarter (Spring) 1987 RI data, supplemented by MKE data from the summer of 1988 for Shell wells.

As described in Section 2.0, VHOs, VHCs, and benzene are present in the unconfined groundwater of water bearing zones 1A and 1 on the north side of the SSA. These volatiles appear to be moving south-southwest from South Plants toward the lakes. Groundwater flows to the southeast as well as the southwest in this area because of the effects of the groundwater mound under South Plants.

The hydraulic gradients are measured from the water table map in Section 1.5. The hydraulic conductivities are from the Water RI Report (Ebasco, 1989/RIC 89067R08). Average values were used for the alluvium and Denver Sands, while the upper limit value was used for Denver claystones to account for the increased secondary permeability.

The VHO plume is shown in Figure SSA 3.5-1. Cross-section B-B' was constructed using data from wells located along the boundary between the SPSA and the SSA, which is approximately perpendicular to the average direction of groundwater flow (Figure SSA 3.5-2). This cross-section indicates that the water table is in the alluvium (Z1) on the west side of the plume, but is in the fractured claystone (Z2) of the Denver Formation along the rest of the section. The bottom of the water bearing zone in this area has been estimated from the well data and is believed to be in the claystone. A Denver Formation sand unit (Z3) is included in the water bearing zone. The total area of saturated material is approximately 140,000 ft<sup>2</sup>. The average hydraulic gradient of the water table in this area is 0.015. The concentrations of VHOs detected in the groundwater along this cross-section range from 10 to 1,000 ug/l.

Three hydraulic conductivities were used for the VHO mass flow rate calculations, 0.02 cm/sec for the alluvium, 0.001 cm/sec for the claystone, and 0.008 cm/sec for the sandstone. The hydraulic conductivity used for the sandstone is from a slug test conducted on Well 01015, which is one of the wells used to construct cross-section A-A'. The hydraulic gradient is 0.015. Using the above parameters, the contaminant mass flow rate for the VHO plume is calculated at 183.4 gms/day.

The VHC plume is also present north of the lakes (Figure SSA 3.5-3). It appears to originate in the SPSA in Section 1, north of Lower Derby Lake. The VHC plume appears to be moving southwest toward Lake Ladora. Cross-section A-A' was constructed using data from wells located in the VHC plume and is orientated approximately perpendicular to the average direction of groundwater flow (Figure SSA 3.5-4). This cross-section indicates that the water table is in the first water bearing zone of the Denver Formation (WBZ 1), which

consists of fractured claystone. The bottom of WBZ 1 in this area is assumed to be the extent of fracturing that was noted on the well logs. The total area of saturated material is approximately 45,000 ft<sup>2</sup>. The average hydraulic conductivity for WBZ 1 is estimated to be 0.001 cm/sec, which is the average value for fractured Denver claystone reported in the Water RI Report (Volume II). The hydraulic gradient for this aquifer is 0.012. The concentrations of total VHCs detected in the groundwater along this cross section range from 5 to 600 ug/l. Using the above parameters, the contaminant mass flow rate for the VHC plume is calculated at 8.5 gms/day.

The benzene plume is present in the same general area as the VHC plume but does not extend as far east (Figure SSA 3.5-5). Cross section A-A' was constructed from the same well data used to construct the cross section for the VHC plume (Figure SSA 3.5-6). As with the VHC plume, the benzene plume is assumed to be located entirely in WBZ 1. The total area of saturated material is approximately 28,000 ft<sup>2</sup>. The average hydraulic conductivity for WBZ 1 is estimated to be 0.001 cm/sec. The hydraulic gradient is 0.012. The concentrations of benzene along the cross section range from 100 to 400,000 ug/l. The contaminant mass flow rate for the benzene plume is calculated at 3,782 gms/day.

### 3.6 INTERIM RESPONSE ACTIONS AND OTHER ONGOING INVESTIGATIONS

Interim Response Actions (IRAs) have been identified and developed by the Army, the USEPA, Shell, and the State of Colorado. Thirteen specific IRAs have been considered "necessary and appropriate" (Federal Facilities Agreement and Settlement Agreement, 1988) to initiate in support of the Record of Decision for both on-post and off-post Operable Units. The IRAs are essentially removal actions, as defined by CERCLA, and are discussed in detail in the proposed Consent Decree and in the Technical Program Plan.

Of the 13 IRAs established for implementation on the RMA, only two, the Abandoned Well Program and the Asbestos Removal Program, will be undertaken in the SSA. The objectives of the Abandoned Well Program were to locate, examine, and properly close old or unused wells on RMA to prevent migration of potential contaminants from upper to lower aquifers (Ebasco, 1988b). The

majority of wells included in the program were limited to those portions of RMA downgradient of known sources of contamination. Consequently, only five wells located in the Section 2 portion of the SSA were considered part of the well abandonment program. The five wells were "pre-1942" wells, and two have subsequently been closed.

The objective of the Asbestos Removal Program is to remove and dispose of friable asbestos from areas or structures where the potential for human exposure exists. Two buildings in the SSA were identified as suspected to contain asbestos. The Buildings RI Report and the RMA Asbestos Abatement Program were used as bases to identify sources requiring remediation.

Additional investigations will be conducted during the scoping of the FS. These include the surface soils investigation and the disturbed areas investigation.

### 3.7 CONCLUSIONS

The RI and other studies conducted in and adjacent to the SSA have provided a large volume of historical, physical, biological, and chemical data from which to characterize the nature and extent of contamination in this part of RMA. These data were evaluated to identify sources of contaminants and were assessed in conjunction with contaminant properties and the hydrogeologic and biologic environment to identify migration pathways and receptors. Subsequently, potentially contaminated soil volumes were calculated for all occurrences of contaminants, and contaminant mass flow rates in groundwater were assessed for mappable plumes of migrating contaminants. From the contamination assessment, the following conclusions may be inferred.

All of the SSA sites contained at least one or more local areas where contaminants were detected. The lakes, ditches, and overflow basins (SSA 1 and SSA 2) contain sources of surface soil, vadose zone, surface water and groundwater contamination by several volatile and semivolatile organic compounds or metals. Many of the organic compounds were frequently detected in the vadose zone and groundwater.

In SSA 3, the buried lakes sediments contained areas of surface and vadose zone contamination but did not appear to be sources of groundwater contamination. Principal contaminants were pesticides or metals.

In SSA 4, the Section 1 trash dump contained areas of surface and vadose zone contaminants which consisted of pesticides and semivolatile organic compounds. Groundwater and surface water do not appear to be impacted by these contaminants.

In SSA 5, the balance of areas investigated, a few discrete areas within the site contained detectable levels of RMA contaminants. Contaminants were detected in water and sediments in southern portions of Sections 11 and 12, however, they may not be attributable to RMA activities. Therefore, they were not considered sources of further contamination within the SSA, nor were the remainder of the areas investigated in SSA 5. There were areas investigated in Section 1 that do contain groundwater potentially contaminated by volatile and semivolatile organic compounds originating from the South Plants area.

Biota collected during the RI program from or near these areas of contamination were found to contain detectable levels of pesticides and metals. Historically, several other groups of volatile and semivolatile organic compounds have also been detected in biota frequently found in the SSA.

Of all the contaminant groups detected in the SSA, OCPs and mercury were the most commonly detected soil and sediment contaminants in the SSA. VHOs, VAOs, and OCPs were widely detected in groundwater flowing into the SSA from the South Plants. VHOs, VAOs, and OCPs were also detected in surface water from ditches exiting South Plants and from ditches entering RMA from the Montbello industrial and residential areas to the south.

Sources in the SSA were classified as containing only surface contaminants (Category 1), surface and vadose zone contaminants (Category 2), or surface, vadose zone, and groundwater contaminants (Category 3). In SSA 1, Category 1 sources include the Rod and Gun Club Pond because of the presence of only some surface contaminants; Category 3 sources include Upper, Lower, and Eastern

Upper Derby Lakes and Lakes Mary and Ladora based on the presence of organic and inorganic contaminants. In SSA 2, only the Section 2 ditches are considered Category 3 because of evidence that OCPs may have migrated through the vadose zone in this subarea to the water table. Section 1 ditches and the overflow basin are Category 2 sites. In SSA 3, the buried lake sediments in both Sections 11 and 12 are Category 2 sites. In SSA 4, the trash dump is a Category 2 site. Other sites in SSA 4 are not considered contaminated. In SSA 5, portions of Section 1 are considered Category 2 sites, while portions of Sections 11 and 12 are Category 1 sites. The balance of areas investigated in Sections 2 and 7 are not considered contaminated.

Following the evaluation of sources, potentially contaminated soil volumes were calculated for all contaminants detected in soils and sediments in the SSA. These estimates were calculated by analyte group based on the concentration ranges depicted in the analyte distribution maps (Section 2.1) and on depth ranges of 0 to 2, 2 to 5, and 5 to 20 ft.

The total estimate of soil potentially contaminated by organic compounds was 940,000 yds<sup>3</sup>. The volumes of soil potentially contaminated by methylene chloride were estimated separately and totalled 49,000 yds<sup>3</sup>. The organic contaminant group with the largest volume was the OCPs, totalling 890,000 yds<sup>3</sup>. Nearly two-thirds of this total (590,000 yds<sup>3</sup>) was attributed to contamination by OCP Subgroup I (aldrin, dieldrin, isodrin, and endrin). About 50 percent of this volume was associated with OCPs found in the sediments of Upper and Lower Derby Lakes. The remainder of the OCP contamination was Subgroup II (DDE, DDT, and chlordane) contamination primarily in the same two lakes.

For inorganic analytes, the estimated volume of potentially contaminated soil with detections above indicator range totalled approximately 570,000 yds<sup>3</sup>. The principal inorganic contaminant detected above its indicator range was mercury, and its distribution was principally associated with lakes, ditches, and dredged sediments.

The primary migration pathway for OCPs, DBCP, arsenic, mercury, and ICP metals is surface water. Many VHOs, VHCs, OSCs, and OPHs were detected in the shallow water bearing zones (WBZ 1 and WBZ 1A) and were also detected in deeper zones (WBZ 2 and WBZ 3). The repeated occurrences of these contaminants in the various water bearing zones suggests that the contaminants have migrated downward through the deeper water bearing zones. Furthermore, the areal distribution of these contaminants suggests that they have migrated laterally as well. Eolian transport may have dispersed OCPs into eastern portions of Section 1, but in general did not significantly affected distribution of analytes from RMA sources.

The volatile compound groups, VHOs, VHCs, and the VAO benzene, were the most common contaminants found in the SSA groundwater. All of the these contaminants have high mobilities and a low affinity for soils. Volatile compounds such as these would most commonly be found in the groundwater, as is the case in the SSA. Plumes were delineated for these contaminants in the water table aquifer. None of the contaminant plumes originate in the SSA and all are found in the north-central area of the SSA, north of the lakes. The plumes appear to be migrating from the SPSA toward Lake Ladora and, to a lesser extent, Lower Derby Lake. Contaminant mass flow rates were calculated for each of these contaminants and the results were: 160 grams/day for VHOs; 0.85 grams/day for VHCs; and 380 grams/day for benzene.

Scattered detections of VHOs and VAOs were also found in water table wells south of the lakes. VAOs were found in the lower Denver Formation aquifers in this same area. The source of these contaminants appears to be off-post to the south. Possible receptors are the surface waters and biota in the lakes and WSA groundwater.

Scattered detections of semivolatile OSCs, OPHs, and DBCP were found in the water table aquifer north of the lakes in the SSA. None of these contaminants was detected extensively and no plumes were delineated. OSCs and DBCP were also detected in the lower Denver Formation aquifers in this area. The sources of all of these contaminants appear to be in the SPSA. These contaminants all have low to moderate solubilities and are moderately mobile.

OPHs and DBCP were also detected south of the lakes in the lower Denver Formation aquifers. The source of these contaminants cannot be the production facilities or disposal sites, as these sources are downgradient from the detections. The sources for these contaminants are probably off-post to the south or possibly analytical or field error in identifying DBCP.

OCPs were detected primarily in water table wells, though scattered hits also occurred in lower Denver Formation aquifers. All OCP detections were north of the lakes, with apparent sources in the SPSA and possibly the ditches in Section 2. Although OCPs have a low water solubility and are not very mobile, they were found in numerous wells associated with the VHOs. The VHOs are apparently contributing to their increased mobility.

Scattered detections of arsenic and mercury were found at relatively low concentrations in all the water bearing zones sampled in the SSA. Arsenic is a naturally occurring mineral and the occurrences in the SSA do not appear to be related to any surface contamination. Mercury is also a naturally occurring mineral, though it would not be common in the SSA due to local geology. However, mercury in the groundwater is not widespread and there is no apparent link to surface contamination.

ICPs were found in every water bearing zone throughout the SSA. However, all of the ICP metals are naturally occurring; their presence does not indicate contamination, and these detections do not correspond with soil contamination, in the SSA.

Potential receptors of several analyte groups include downstream sediments, surface waters, and downgradient groundwater. The potential receptors of any of the groundwater contaminants detected in the SSA are the surface waters and biota of Lake Ladora and Lower Derby Lake and the downgradient groundwater in the WSA and the ESA. However, as the contaminants move into cleaner water bearing zones, their concentrations will decrease and they may not be detected in either the WSA or the ESA. The lower Denver Formation aquifers may also be receptors of these contaminants; scattered detections were found in these aquifers throughout the SSA. Downgradient surface water and surface sediments



are likely receptors of metals, OCPs, and SHOs. Some potential exists for uptake of OCPs, mercury, and copper by terrestrial organisms, vegetation, and aquatic organisms. The potential is most probable in aquatic ecosystems where contact via several pathways exists.

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